PB83-247171

HSPF (Hydrological Simulation Program--FORTRAN) Parameter Adjustments to Evaluate the Effects of Agricultural Best Management Practices

Anderson-Nichols and Co., Inc., Palo Alto, CA

Prepared for

Environmental Research Lab., Athens, GA

Aug 83

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/3-83-066		PB83-247171

4. TITLE AND SUBTITLE	5. REPORT DATE
HSPF Parameter Adjustments to Evaluate the Effects of Agricultural Best Management Practices	August 1983
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Anthony S. Donigian, Jr.,* James L. Baker,** Douglas A. Haith and Michael F. Walter***	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
*Anderson-Nichols and Co., Palo Alto, CA 94304 **Iowa State University, Ames, IA 50011 ***Cornell University, Ithaca, NY 14853	AARB1A
	11. CONTRACT/GRANT NO.
	68-03-2895
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Environmental Research Laboratory--Athens GA Office of Research and Development U.S. Environmental Protection Agency Athens, GA 30613	Final
	14. SPONSORING AGENCY CODE
	EPA/600/01

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report describes a research effort to quantitatively assess the effects of selected agricultural practices on runoff, erosion and chemical processes, and to quantify the associated adjustments to model parameters based on the current state-of-the-art. Although the specific parameter changes are particular to the EPA's Hydrological Simulation Program--FORTRAN (HSPF) and Agricultural Runoff Management (ARM) Model used in this study, the information presented is generally applicable and should be pertinent to many models with similar representations of the relevant processes.

Conventional practices and candidate BMPs for watersheds in Iowa are discussed as a basis for predicting BMP impacts on relevant processes. Guidelines and recommendations are included for adjusting all major parameters whose effects can be reasonably quantified. Deficiencies in the current state of knowledge of BMP effects and recommendations for future research and model improvements are discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	116
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

PB83-247171

EPA-600/3-83-066
August 1983

HSPF PARAMETER ADJUSTMENTS TO EVALUATE THE EFFECTS OF AGRICULTURAL BEST MANAGEMENT PRACTICES

by

Anthony S. Donigian, Jr.
Anderson-Nichols & Co.
Palo Alto, CA 94304

James L. Baker
Iowa State University
Ames, IA 50011

Douglas A. Haith
Michael F. Walter
Cornell University
Ithaca, NY 14853

Contract No. 68-03-2895

Project Officer

Thomas O. Barnwell
Technology Development and
Applications Branch
Environmental Research Laboratory
Athens, Georgia 30613

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ATHENS, GEORGIA 30613

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract Number 68-03-2895 to Anderson-Nichols and Co. It has been subject to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the United States Environmental Protection Agency.

FOREWORD

As environmental controls become more costly to implement and the penalties of judgment errors become more severe, environmental quality management requires more efficient analytical tools based on greater knowledge of the environmental phenomena to be managed. As part of this Laboratory's research on the occurrence, movement, transformation, impact, and control of environmental contaminants, the Technology Development and Applications Branch develops management or engineering tools to help pollution control officials achieve water quality goals.

The Hydrologic Simulation Program--FORTRAN (HSPF), developed through Athens Laboratory research, is a comprehensive technique for modeling water quality constituents in runoff from various land uses. To test the model's capabilities in evaluating the effects of agricultural best management practices (BMPs) on water quality, HSPF was applied to two watersheds in Iowa. The test demonstrated that HSPF is a flexible and realistic technique for BMP assessment in small watersheds and large river basins. Coupled with risk assessment procedures, the model can provide data for use in evaluating impacts of pollutants on selected aquatic organisms.

William T. Donaldson
Acting Director
Environmental Research Laboratory
Athens, Georgia

ABSTRACT

Mathematical models of agricultural runoff processes are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) plan that will maintain agricultural productivity while minimizing adverse water quality impacts. The key problem with most models, and especially those with an empirical basis, is how to adjust model parameters to represent the effects of a specific practice, or combination of practices, that comprise a BMP.

This report describes a research effort to qualitatively assess the effects of selected agricultural practices on runoff, erosion, and chemical processes, and to quantify the associated adjustments to model parameters based on the current state-of-the-art. Although the specific parameter changes are particular to the EPA's Hydrological Simulation Program-FORTRAN (HSPF)(Johanson et al, 1980) and Agricultural Runoff Management (ARM) models used in this study, the information presented is generally applicable and should be pertinent to many models with similar representations of the relevant processes.

Conventional practices and candidate BMPs for watersheds in Iowa are discussed as a basis for predicting BMP impacts on relevant processes. Guidelines and recommendations are included for adjusting all major parameters whose effects can be reasonably quantified. Deficiencies in the current state of knowledge of BMP effects and recommendations for future research and model improvements are presented and discussed.

This report was submitted by Anderson-Nichols & Co. in partial fulfillment of Contract No. 68-03-2895 under the sponsorship of the U.S. Environmental Protection Agency. The work was completed as of November 1980.

CONTENTS

Section		Page
Abstract		iv
Figures		vi
Tables		vii
Acknowledgments		viii
1.	Introduction	1
	1.1 Background	1
	1.2 Mathematical Modeling	3
	1.3 This Report	4
2.	Modeling Soil and Runoff Processes with HSPF PERLND	5
	2.1 Introduction	5
	2.2 Modeling Chemical Movement Over and Through the Soil	5
	2.3 Hydrology Simulation	8
	2.4 Sediment Erosion Simulation	9
	2.5 Pesticide Simulation	14
	2.6 Nutrient Simulation	16
	2.7 Differences Between HSPF PERLND and ARM II	20
3.	Methodology for Evaluating BMP Impacts	22
	3.1 Introduction	22
	3.2 Conventional Practices and Candidate BMP's	22
	3.3 Agricultural Runoff Processes/Components and BMP's	25
	3.4 BMP's and HSPF Parameters	28
4.	HSPF Parameter Guidelines and Values for BMP's in Iowa	31
	4.1 Introduction	31
	4.2 HSPF Runoff Parameters	32
	4.3 HSPF Sediment Parameters	47
	4.4 HSPF Chemical Parameters	62
	4.5 BMP's Requiring Special Considerations for Simulation with HSPF	76
5.	Recommendations for Future Research	82
	5.1 Practice-Oriented Research	82
	5.2 Process and Parameter Research	83
	5.3 Model Development Research	84
6.	References	87
7.	Appendix	96
	Working Definitions of Candidate BMP's	97
	HSPF and Corresponding ARM Model Parameters Related to Processes Impacted by BMP's	101

FIGURES

Figure		Page
1.1	Location of Four Mile Creek and Iowa-Cedar River Basin Sites for Iowa Field Evaluation Program	2
2.1	Pervious Land-segment Application Module.	6
2.2	Pesticide and Nutrient Movement in the PERLND Module of HSPF	7
2.3	Flow Diagram for SEDMNT Section of PERLND Application Module.	10
2.4	Sample Land Cover Functions With and Without Crop Residues	13
2.5	Flow Diagram for Nitrogen Reactions	18
2.6	Flow Diagram for Phosphorus Reactions	19
4.1	Crop Canopy Development Functions	33
4.2	Typical Flow Paths for Natural and Terrace Flow Systems.	78

TABLES

Table		Page
3.1	Candidate Best Management Practices	24
3.2	Relative Impact of Selected BMPs on Agricultural Runoff Processes/Components Compared to Conventional Practices.	26
3.3	Relative Impact of Selected BMPs on HSPF Parameters	29
4.1	Method for Converting Crop Yields to Residue. . . .	35
4.2	Residue Reduction from Tillage Operations	35
4.3	Values of UZSN for Selected BMPs on Tama Silty Clay Loam	38
4.4	Values of 'a' for Equation (4.8).	42
4.5	Upper Bound Estimates of INFILT for Selected BMPs on Tama Silty Clay Loam	45
4.6	Properties of Tama Silty Clay Loam.	49
4.7	Crop Rotation Effect on KRER.	49
4.8	Summary of Change in KRER Over a Long Period Due to Continuous Application of Practices.	49
4.9	P Values and Slope-Length Limits for Contouring.	53
4.10	P Values, Maximum Strip Widths, and Slope-Length Limits for Contour Strip Cropping.	53
4.11	P Values for Contour-Farmed Terraced Fields	53
4.12	Values of 'a' for Determination of Overland Flow Sediment Coefficients.	61
4.13	Effect of Application Method on Fertilizer and Pesticide Distribution in the Soil Profile. . .	66
4.14	Temperature Decreases (degrees C) for Two Levels of Corn Residue on the Soil Surface Relative to None.	75

ACKNOWLEDGEMENTS

This work was sponsored and supported by the U.S. Environmental Protection Agency. Mr. Thomas Barnwell of the Environmental Research Laboratory, Athens, GA. was Project Officer; his assistance and guidance has contributed to the successful completion of this work and is gratefully acknowledged. In addition, the technical review and guidance from Mr. Lee Mulkey and Mr. Charles Smith, also from the Athens Laboratory, has proven invaluable in this work.

Among the authors, Mr. Donigian was responsible for the overall direction of the project and technical guidance on the HSPF modeling aspects. Drs. Baker, Haith, and Walter provided the expertise related to the chemical, runoff, and sediment parameters, respectively, and developed the associated parameter evaluation guidelines and recommendations. A project team approach was used in this work with all authors participating in meetings and preparation of the final report.

At Anderson-Nichols, Mr. John Imhoff assisted in the BMP selection, definition, and qualitative analyses. Ms. Mary Maffei and Ms. Barbara Wereda provided clerical support, Mr. Brian Bicknell performed the text processing, and Ms. Lynn Wollenweber provided graphics support and drafting expertise. The dedication and efforts of these individuals is sincerely appreciated.

SECTION 1

INTRODUCTION

Mathematical models of agricultural runoff processes are being used to analyze and predict the quantity and quality of runoff from agricultural lands. The ultimate goal is to use these models to develop a Best Management Practice (BMP) plan that will maintain agricultural productivity while minimizing adverse water quality impacts. The key problem with most models, and especially those with an empirical basis, is how to adjust model parameters to represent the effects of a specific practice, or combination of practices, that comprise a BMP.

This report describes a research effort to qualitatively assess the effects of selected agricultural practices on runoff, erosion, and chemical processes, and to quantify the associated adjustments to model parameters based on the current state-of-the-art. Although the specific parameter changes are particular to the EPA's Hydrological Simulation Program-FORTRAN (HSPF)(Johanson et al, 1980) and Agricultural Runoff Management (ARM) models (Donigian and Crawford, 1976; Donigian et al, 1977; Donigian and Davis, 1978) used in this study, the information presented is generally applicable and should be pertinent to many models with similar representations of the relevant processes.

1.1 Background

The research and results presented in this report were performed as part of a comprehensive Field Evaluation Program (FEP) (U.S. EPA, 1979), sponsored by EPA and coordinated by the Athens Environmental Research Laboratory, whose primary purposes were to test and demonstrate (1) the capability of agricultural best management practices to achieve water quality goals, and (2) the applicability of two water quality planning tools - HSPF and the Chemical Migration and Risk Assessment (CMRA) methodology (Onishi et al., 1979) to the BMP evaluation and selection process.

These objectives of the FEP were planned to be accomplished through a series of studies in the Iowa-Cedar river basin in the State of Iowa (Figure 1.1). The primary focus of the FEP was the Four Mile Creek basin near Traer, Iowa, a 20 square mile agricultural watershed that has been the site of a study of sediment, nutrient, and pesticide fate and transport by EPA and Iowa State University.

Extensive field monitoring and data collection programs at the Four Mile Creek site supported the FEP to provide the necessary

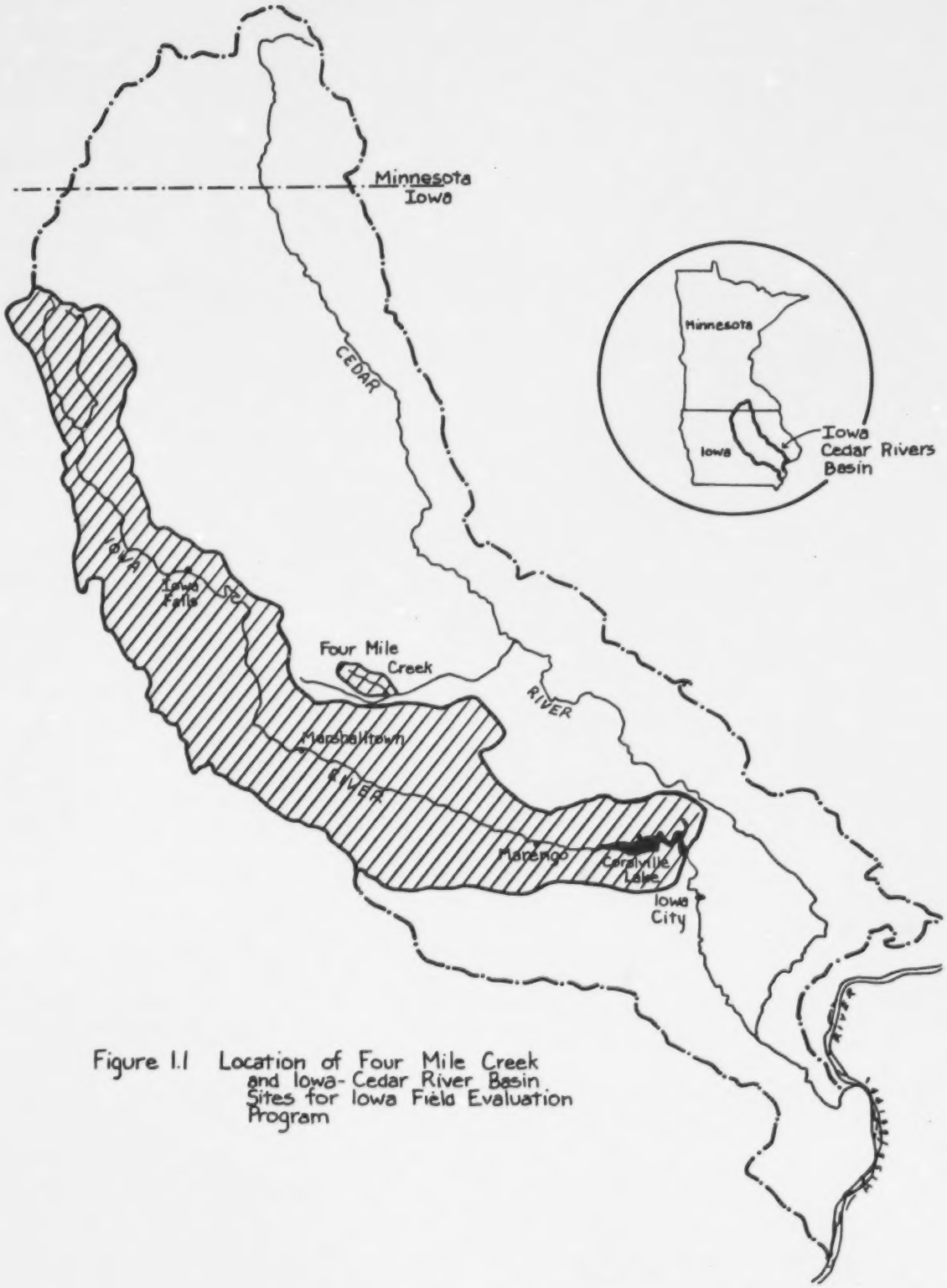


Figure 1.1 Location of Four Mile Creek and Iowa-Cedar River Basin Sites for Iowa Field Evaluation Program

data for the BMP analysis and modeling efforts. HSPF and CMRA were then applied to the 3000 square mile Iowa River above Coralville Reservoir to demonstrate the planning methodologies on a large river basin. The study included the participation of local farmers in Four Mile Creek site and local, state, and federal agencies in order to demonstrate the BMP evaluation, selection, and implementation process.

1.2 Mathematical Modeling

Both HSPF and the CMRA methodolcgy were applied in the Iowa FEP to evaluate and demonstrate their utility for BMP analyses. HSPF is a comprehensive program for modeling runoff, sediment, pesticides, nutrients, and other water quality constituents from urban, agriculture, and other land uses. It allows detailed simulation of stream hydraulics, water quality constituents, pesticide and nutrient behavior in soil, lake reservoir dynamics, and sediment-contaminant transport. It also includes extensive data handling and analysis procedures that support and complement the simulation capabilities. The modeling of land surface and soil processes, which are affected by agricultural practices and are of primary importance in this report, is performed by the PERLND (pervious land segment) section of HSPF. PERLND is essentially a translation and restructuring of the ARM model algorithms with some additional improvement and extensions.

The CMRA methodology provides procedures for detailed instream simulation of sediment and chemical transport and interactions to develop time series of chemical concentrations in streams. The time series is then characterized by a frequency-duration relationship for use with toxicity data to assess the frequency of acute and chronic toxic conditions for aquatic organisms. The CMRA methodology is comprised of four components: the ARM model is used to simulate pesticide loading to the stream; the EXPLORE model (Baca et al., 1973) simulates stream hydraulics; the SERATRA model (Onishi and Wise, 1979) simulates instream sediment transport, contaminant decay mechanisms, and sediment-contaminant interactions; and the FRANCO model (Olsen and Wise, 1979) performs frequency analyses of the contaminant concentration time series in order to assess the relative occurrence of acute and chronic toxic conditions.

Since both HSPF and CMRA include the ARM model functions and identical statistical capabilities, there is some duplication in the models. As part of the modeling effort, HSPF was modified to include the basic SERATRA and FRANCO model capabilities in order to provide a single comprehensive system to analyze water quality and toxic conditions for assessing the aquatic impact of candidate BMPs.

1.3 This Report

This report describes the research performed to quantify the adjustments in HSPF model parameters in order to represent the primary effects of selected candidate BMPs in the Iowa watersheds. The work is based entirely on the current literature and development of relationships between relevant HSPF model parameters and existing data on BMPs. In cases where data or research was lacking, parameter guidelines are based on the best judgement of the authors.

The primary output of this research effort is the parameter evaluation guidelines and values provided in Section 4.0 for the HSPF runoff, sediment, and chemical parameters for selected candidate BMPs. In many cases the specific parameter values are pertinent only to the Iowa watershed, while the guidelines describe how to estimate parameter values for other areas or conditions.

Section 2.0 provides a brief description of the HSPF PERLND algorithms relevant to the surface and soil processes affected by agricultural management practices. The step-by-step procedures we followed in this research are discussed in Section 3.0, along with a presentation of the relative (qualitative) impacts of selected BMPs on agricultural runoff processes and components, and related HSPF parameters. This qualitative assessment provided the basis for the quantitative guidelines and parameter values in Section 4.0. Section 5.0 presents recommendations for needed research to provide data for model parameter evaluation, to expand our quantitative understanding of the impacts of BMPs, and to improve the model's representation of specific processes.

SECTION 2

MODELING SOIL AND RUNOFF PROCESSES WITH HSPF PERLND

2.1 Introduction

In HSPF, the Pervious Land Segment module (PERLND) simulates the water quality and quantity processes which occur on pervious land areas, and which provide flow, sediment, and chemical contributions to a stream channel from surface and subsurface sources. Figure 2.1 is the structure chart of the PERLND module showing the component module sections and associated functions. Of primary concern in this study are the SNOW, PWATER, and SEDMNT module sections that include the hydrologic and sediment erosion modeling capabilities, and the agri-chemical module sections (i.e. MSTLAY, PEST, NITR, PHOS, TRACER) that simulate the fate, transformations, and runoff of pesticides, nutrients, and non-reactive tracer chemicals.

This section of the report discusses the overall representation of the fate and movement of agricultural chemicals in HSPF and the specific algorithms included in the hydrology, sediment, pesticide, and nutrient modules to provide a foundation for presenting the effects of selected management practices on the model parameters. More detail on specific algorithms can be found in the HSPF user manual and the ARM model reports. In HSPF, the ARM Version II algorithms (Donigian et al., 1977; Donigian and Crawford, 1979) were recreated with some additional options and enhancements. The primary differences between HSPF and ARM II are summarized in Section 2.7.

2.2 Modeling chemical movement over and through the soil

The transport and vertical movement of pesticides and nutrients, as conceived in the PERLND module is indicated in Figure 2.2. Pollutant contributions to the stream can occur from the surface zone, the upper zone, and groundwater zone. Surface runoff is the primary transport mechanism carrying sediment, adsorbed chemicals, pesticide particles, and some dissolved chemicals. The interflow component of runoff can transport dissolved pesticides or nutrients occurring in the upper zone. Vertical chemical movement between the soil zones is the result of infiltrating and percolating water. From the vertical soil layers, uptake and transformation of nutrients and degradation of pesticides is allowed. The active groundwater layer receives percolating water and associated dissolved chemicals which then reach the stream channel with the groundwater flow component.

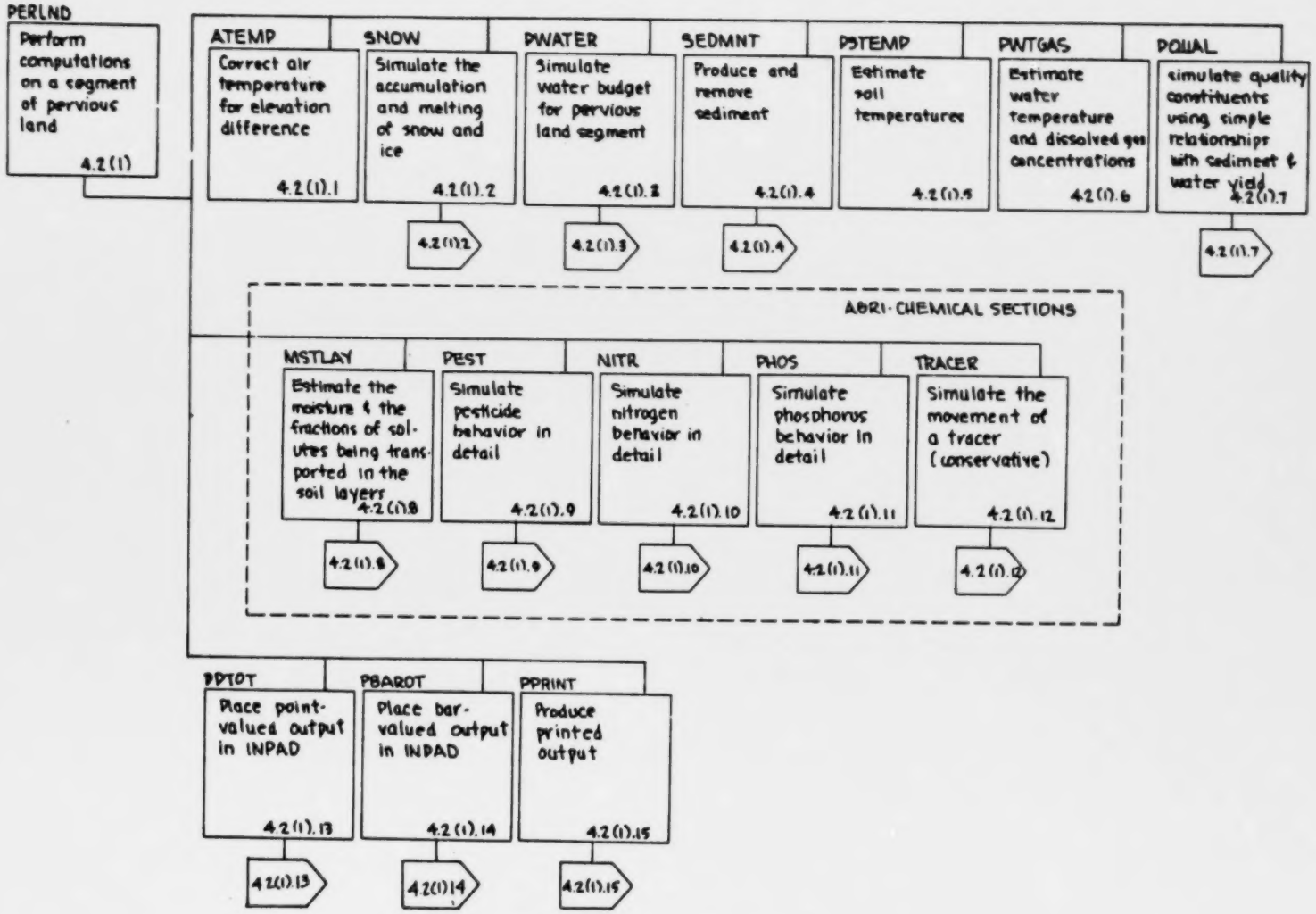


Figure 2.1 Pervious land-segment application module

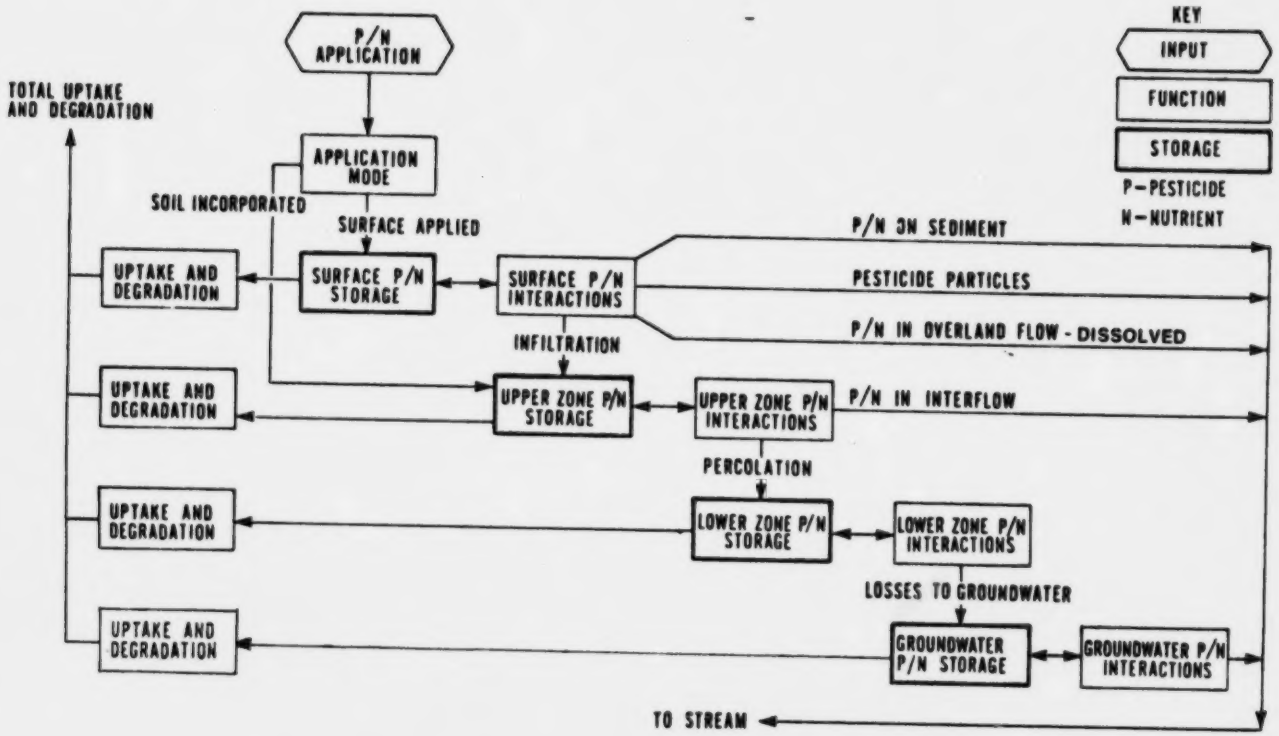


Figure 2.2 Pesticide (P) and nutrient (N) movement in the PERLND module of HSPF

In order to simulate vertical movement and transformations of pesticides and nutrients in the soil profile, specific soil layers (and depths) are established so that the total soil mass in each layer can be computed. Total soil mass is a necessary ingredient in the pesticide adsorption/desorption reactions and nutrient transformations. The vertical soil layers simulated in PERLND include the surface, upper, lower, and groundwater zones. The depths of the surface and upper soil zones are specified by the model input parameters, and are generally in the range of 2-8 mm and 75-150 mm, respectively. The upper zone depth corresponds to the depth of the incorporation of soil-incorporated chemicals. It also indicates the depth used to calculate the mass of soil in the upper zone whether agricultural chemicals are soil-incorporated or surface-applied.

The lower zone and groundwater depths are also specified as model input parameters. The lower zone reaches from the bottom of the upper zone to the top of the capillary fringe of the active groundwater layer. The thickness of the groundwater layer corresponds to the thickness of the groundwater aquifer actively contributing to groundwater or base flow in the watershed.

2.3 Hydrology simulation

As noted above, the hydrologic simulation methodology in the PERLND module was derived from the ARM model, which in turn derived its functions from the Stanford Watershed Model (Crawford and Linsley, 1966) and the Hydrocomp Simulation Program, HSP (Hydrocomp, Inc., 1976). The ATEMP, SNOW, and PWATER module sections of HSPF jointly perform the functions of the LANDS subprogram of the ARM model and HSP. Through a linked set of theoretical and empirical mathematical functions, the PWATER module section simulates the land surface and soil processes of the hydrologic cycle including interception, surface detention, soil moisture storage, surface runoff, infiltration, interflow, evapotranspiration, percolation to groundwater, and groundwater outflow. The SNOW module section performs energy (heat) balance calculations based on input meteorologic data to simulate the various physical processes that determine snow accumulation and melt.

The algorithms for the specific hydrologic processes affected by agricultural conditions and management practices will be discussed in Section 4 as they relate to parameter evaluation. Complete descriptions of all algorithms can be found in the HSPF User Manual and the ARM model references.

2.4 Sediment erosion simulation.

Module Section SEDMNT simulates the production and removal of sediment from pervious land areas based on the input rainfall, the PWATER simulation of overland flow, and the input model parameters describing the soil characteristics and land surface conditions as affected by agronomic practices. The equations used to produce and remove sediment are based on the ARM and NPS Models (Donigian and Crawford 1976 a,b). The algorithms representing land surface erosion in these models were derived from a sediment model developed by Negev (1967) and influenced by Meyer and Wischmeier (1969) and Onstad and Foster (1975).

Figure 2.3 (from the HSPF User Manual) schematically represents the sediment fluxes and storages used to simulate the detachment, attachment, and removal processes involved in sediment erosion from the land surface. Removal of sediment by water is simulated as washoff of detached sediment in storage (WSSD) and scour of matrix soil (SCRSD). The washoff process involves two parts: the detachment/attachment of sediment from/to the soil matrix and the transport of this sediment. Detachment (DET) occurs by rainfall. Attachment occurs only on days without rainfall; the rate of attachment is specified by parameter AFFIX. Transport of detached sediment is by overland flow. The scouring of the matrix soil includes both detachment and transport by overland flow combined into one process.

Kinetic energy from rain falling on the soil detaches particles which are then available to be transported by overland flow. The equation that simulates detachment is:

$$DET = DELT60*(1.0 - CR)*SMPF*KRER*(RAIN/DELT60)**JRER \qquad (2.1)$$

where:

- DET = sediment detached from the soil matrix by rainfall in tons/acre per interval
- DELT60 = number of hr/interval
- CR = fraction of the land covered by snow and other cover on a specific day
- SMPF = supporting management practice factor
- KRER = detachment coefficient dependent on soil properties
- RAIN = rainfall in in./interval
- JRER = detachment exponent dependent on soil properties

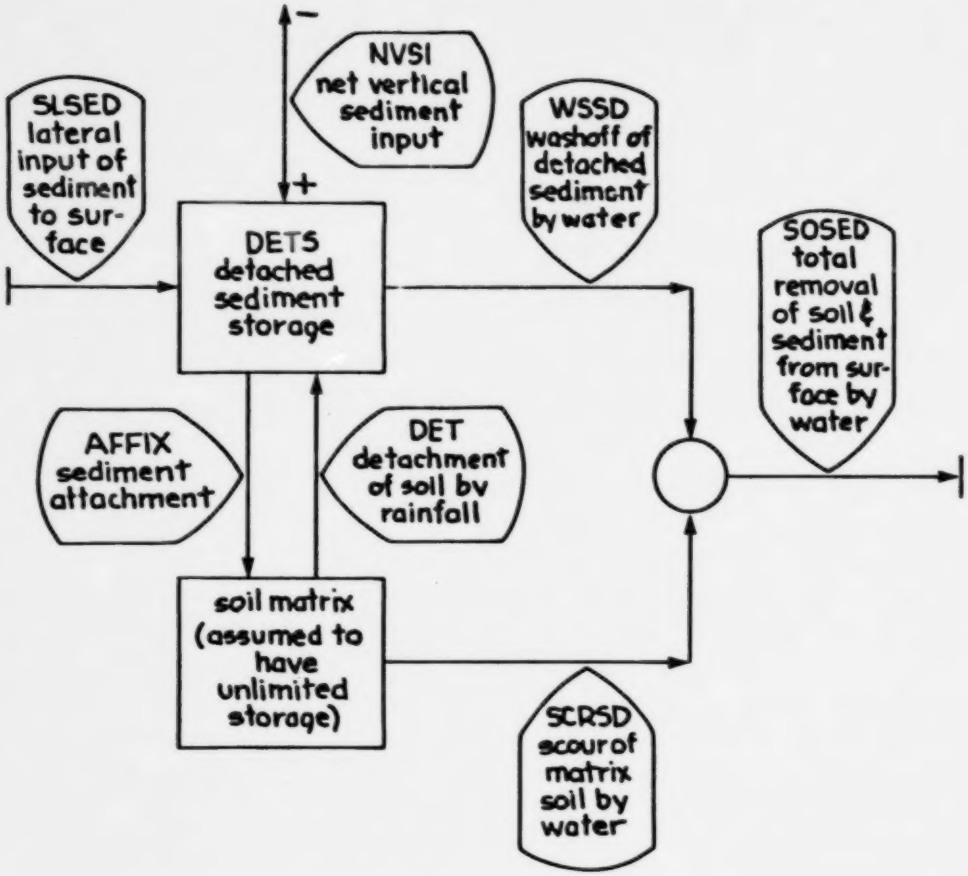


Figure 2.3 Flow diagram for SEDMNT section of PERLND Application Module.

The supporting management practice factor which has been added to the soil detachment equation was based on the 'P' factor in the Universal Soil Loss Equation (Wischmeier and Smith, 1978). It was introduced in order to better evaluate agricultural conservation practices.

The value of DET calculated above is added to the total detached sediment, DETS, in each interval with the resulting total available for transport by overland flow. On nonrain days, DETS is reduced as follows:

$$DETS(T) = DETS(T-1)*(1.0 - AFFIX) \quad (2.2)$$

where

DETS(T) = detached sediment storage on day T, tons/acre
DETS(T-1) = detached sediment storage on day T-1, tons/acre
AFFIX = fraction reduction in detached sediment storage, per day

AFFIX decreases the detached sediment storage due to the combined affects of settling and aggregation of soil particles, and compaction by rainfall and agricultural operations. It is a simple approximation to complex processes that depend on soil characteristics, meteorologic conditions, and agricultural practices.

When simulating the washoff of detached sediment, the transport capacity of the overland flow is estimated and compared to the amount of detached sediment available. Sediment washoff is assumed to occur at the transport capacity unless it is limited by the available detached sediment. The transport capacity is calculated by the equation:

$$STCAP = DELT60*KSER*((SURS + SURO)/DELT60)**JSER \quad (2.3)$$

where:

STCAP = capacity for removing detached sediment in tons/acre per interval
DELT60 = hr/interval
KSER = coefficient for transport of detached sediment
SURS = surface water storage in inches
SURO = surface outflow of water in in./interval
JSER = exponent for transport of detached sediment

When STCAP is greater than the amount of detached sediment in storage, washoff is calculated by:

$$WSSD = DETS*SURO/(SURS + SURO) \quad (2.4)$$

If the storage is sufficient to fulfill the transport capacity, then the following relationship is used:

$$WSSD = STCAP*SURO/(SURS + SURO) \quad (2.5)$$

where:

WSSD = washoff of detached sediment in tons/acre per interval

DETS = detached sediment storage in tons/acre

Since STCAP is calculated as a function of both surface water storage (SURS) and outflow (SURO), the sediment contribution in each time interval (WSSD) depends on the fraction of water reaching the outlet in each time interval (SURO/(SURS + SURO)), as shown in Equations 2.4 and 2.5. WSSD is then subtracted from DETS to determine the available detached sediment for the next time step.

Monthly cover values as of the first day of the month are specified by the user by the cover parameter. The model interpolates linearly between the monthly values to evaluate land cover on each day to determine the value of CR in Equation 2.1. Figure 2.4 demonstrates the land cover function in the model. The kinetic energy of rainfall is effectively dissipated by the land cover with values of 90 to 95 percent of the area. Thus, judicious use of the land cover function allows simulation of various land surface conditions for different practices.

The timing and severity of tillage operations have a controlling effect on the sediment loss from an agricultural watershed. With regard to sediment production, the effect of tillage operations is to decrease protection provided by surface cover, increase the mass of detached soil fines available for transport, and produce a reasonably uniform distribution of fines across the watershed. Consequently, HSPF allows the user to specify the dates of tillage, planting, or other land-surface disturbing operations. (The HSPF 'Special Actions' option is used for this purpose; see Section 2.7 and the HSPF User Manual for more details). For each of these dates the user can specify new land cover and detached soil fines storage values resulting from the operation. At the time of tillage HSPF resets the cover and fines storages to the new values resulting in a new fines distribution across the watershed. The amount of fines storage produced by different tillage operations is related to the depth and extent of the operation and edaphic characteristics.

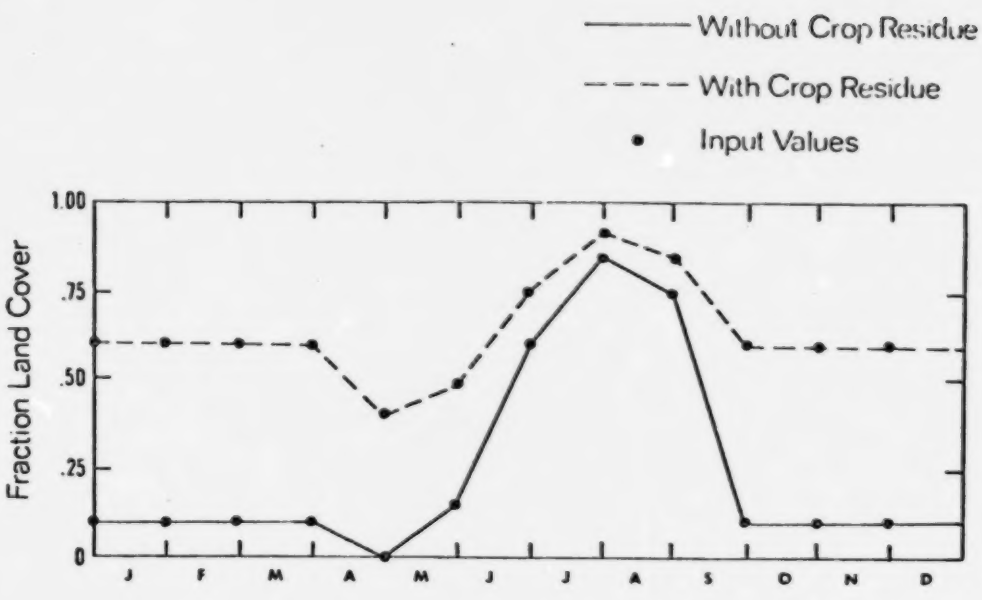


Figure 2.4 Sample Land Cover Functions With and Without Crop Residue

Transport and detachment of soil particles from the soil matrix is simulated with the following equation:

```
SCRSD = SURO/(SURS + SURO)*DELT60*KGER*
        ((SURS + SURO)/DELT60)**JGER                    (2.6)
```

where:

SCRSD = scour of matrix soil in tons/acre per interval
KGER = coefficient for scour of the matrix soil
JGER = exponent for scour of the matrix soil

The sum of the two fluxes, WSSD and SCRSD, represents the total sediment outflow from the land segment. The formulation for SCRSD in Equation 2.6 was derived from Negev's original work and was not included in the ARM or NPS models.

Since land cover by growing crops and crop residues has a major impact on sediment loss, the variability in the land surface cover is explicitly represented in the PERLND. The land cover variable in Equation 2.1, CR, represents the combined effect of the fraction of the area covered by the snowpack (SNOCOV), if any, and the fraction covered by anything else but snow (COVER). SNOCOV is computed in the snow simulation routines in section SNOW. COVER is a parameter that represents the fraction of the land surface effectively protected from the kinetic energy and detachment capability of rainfall by vegetation, mulch, crop residues, jute matting, etc. Abrupt changes to COVER can be effected through the Special Actions option (see Section 2.7).

2.5 Pesticide simulation

Using the moisture movement and runoff simulation from section PWATER and the sediment erosion simulation from section SEDMNT, the PEST section simulates the adsorption/ desorption process, vertical movement, decay, and resulting runoff contributions of a pesticide. The process of pesticide adsorption/desorption onto sediment particles is a major determinant of the amount of pesticide loss that will occur. This process establishes the division of available pesticide between the water and sediment phases, and thus specifies the amounts of pesticide transported in solution and on sediment.

In section PEST, HSPF allows the user to simulate the adsorption/desorption process with either an equilibrium isotherm or separate first-order rate constants. The isotherm approach uses the following equation:

```
X   = KF1*C**(1/N1) + XFIX                              (2.7)
```

where:

X = chemical adsorbed on soil, in ppm of soil
KF1 = single value Freundlich K coefficient
C = equilibrium chemical concentration in solution, in ppm of solution
N1 = single value Freundlich exponent
XFIX = chemical which is permanently fixed, in ppm of soil

This algorithm is comprised of an empirical term, XFIX, plus the standard Freundlich single-valued (SV) adsorption/desorption isotherm. The empirical term accounts for portions of certain pesticides (e.g., fonofos, paraquat) that are permanently adsorbed to soil particles and will not desorb under repeated washing. The input parameters KF1, N1, and XFIX can be specified separately for each soil layer.

Like the ARM Model, HSPF includes an option to use a non-single-valued (NSV) adsorption/desorption function because research has indicated that the assumption of single-valued adsorption/desorption may not be valid for many pesticides (Davidson, et al., 1973). In these cases, the adsorption and desorption processes result in different pesticide concentrations. The form of the desorption equation is identical to Equation 2.7 except that KF1 and N1 values are replaced by KF2 and N2 respectively. The user specifies the N2 value as an input parameter and the model calculates KF2 as a function of the adsorption/desorption parameters (KF1, N1, N2) and the pesticide solution concentration (Davidson, et al., 1973). The NSV function simulates higher pesticide concentrations on sediment than the SV function in order to represent the irreversibility of the adsorption process.

With the option for first-order kinetics, section PEST recalculates the distribution of the pesticide between the sediment and solution phases in each calculation interval based on the fluxes specified by the input reaction rates.

The calculation of adsorption and desorption reaction fluxes by first-order kinetics for soil layer temperatures less than 35 degrees C takes the form:

```
DES = CMAD*KDS*THKDS**(TMP - 35.0)          (2.8)
ADS = CMSU*KAD*THKAD**(TMP - 35.0)          (2.9)
```

where:

DES = current desorption flux of chemical in mass/area per interval
CMAD = storage of adsorbed chemical in mass/area
KDS = first-order desorption rate parameter, per interval
THKDS = temperature correction parameter for desorption

TMP = soil layer temperature in degrees C
ADS = current adsorption flux of chemical in mass/area per interval
CMSU = storage of chemical in solution in mass/area
KAD = first-order adsorption rate parameter, per interval
THKAD = temperature correction parameter for adsorption

THKDS and THKAD are typically about 1.04 to 1.06 (Reddy et al, 1979).

All of the variables except the temperature coefficients may vary with the layer of the soil being simulated. The soil temperatures are time series which may be input (e.g., using field data) or simulated in module section PSTEMP. The temperature correction of the reaction rate parameter is based on the Arrhenius equation. At temperatures of 35 degrees C or above no correction is made. When the temperature is at 0 degrees C or below, or the soil layer is dry, no adsorption and desorption occurs. This option for first-order kinetics for pesticide adsorption/desorption has not been tested extensively since it was not included in the ARM model.

Attenuation of applied pesticides, through volatilization and degradation processes, is critical to the accurate simulation of pesticide runoff because these mechanisms control the amount of chemical available for transport. These processes are not well understood and are topics of continuing research. To approximate the pesticide attenuation following application, HSPF includes a first-order attenuation function that allows the use of different degradation rates (through the 'Special Actions' option) for separate time periods after application. The function calculates the combined degradation of pesticides by volatilization, microbial degradation, and other attenuation mechanisms. This approach was chosen after evaluating both simpler and more sophisticated degradation models (Donigian, et al., 1977). Unlike the ARM model, HSPF allows different degradations for each soil layer. This capability allows the use of higher decay rates in the surface layer where the pesticide may undergo volatilization, photochemical decay, and microbial decay, and lower rates in the subsurface layers where microbial degradation is the primary mechanism.

2.6 Nutrient simulation.

Nutrient simulation by the NUTR module sections of HSPF attempts to represent the reactions and transformations of nitrogen and phosphorus compounds in the soil profile as a basis for predicting the nutrient content of agricultural runoff. As in the PEST section, moisture and sediment movement values are transferred from the associated modules to provide the moisture

storage and transport values needed for the nutrient simulation. The nutrient model primarily assumes first-order reaction rates and is derived from work by Mehran and Tanji (1974), and Hagin and Amberger (1974). The processes simulated include immobilization, mineralization, nitrification/denitrification, plant uptake, and adsorption/ desorption (for which an equilibrium isotherm option is available). In the model, fertilizer, plant residue, or animal waste is applied in their chemical form (NH4, NO3, PO4, Cl, and organic N and P) to the land surface or into the soil.

The NITR section simulates nutrient movement in the watershed by water or sediment. Transformations of nutrients determine the nutrient forms in each soil layer and their resulting susceptibility to movement. Nutrient transport processes are simulated only to the extent that is needed to predict runoff quality and quantity. The model does not consider the generally secondary movement of soil chemicals by concentration and thermal gradients. However, it does model the lateral and downward transport of chemicals by water from the soil zones. Lateral transport of nutrients towards the stream can occur from the surface and upper zone storages. Inflow of nutrients to the groundwater zone and nutrient transformations in the groundwater are modeled as a basis for predicting the outflow of dissolved constituents with groundwater flow.

Figures 2.5 and 2.6 diagram the transformation pathways and storages and show the names of the reaction rate input parameters and formulation. (For example, in Figure 2.5 the temperature-corrected nitrogen plant uptake rate is KPLNK, and the associated input parameter is KPLN). Reaction rates are input on a per day basis for each soil layer. Nitrite (NO2) transforms so quickly in most agricultural areas that it is not considered separately. The adsorbed phase represents the nutrients in a complex form along with those adsorbed on the soil. The plant uptake rates (KPL) are input monthly as a function of the stage of crop growth. These monthly uptake parameters are adjusted to represent the crop uptake of N and P from the soil storages and to distribute it throughout the growing season.

Soil temperature is presently the only environmental factor that is modeled as affecting the reaction rates, with the exception that the transformations are stopped entirely at very low moisture levels. Soil temperatures for the surface and upper zones are determined by regression equations based on air temperature, while the daily soil temperature for the lower zone and groundwater is interpolated from average monthly input values. Other factors deemed as having a constant influence during the simulation period, such as soil pH, are represented by adjustments to the input reaction rates. Also, all input

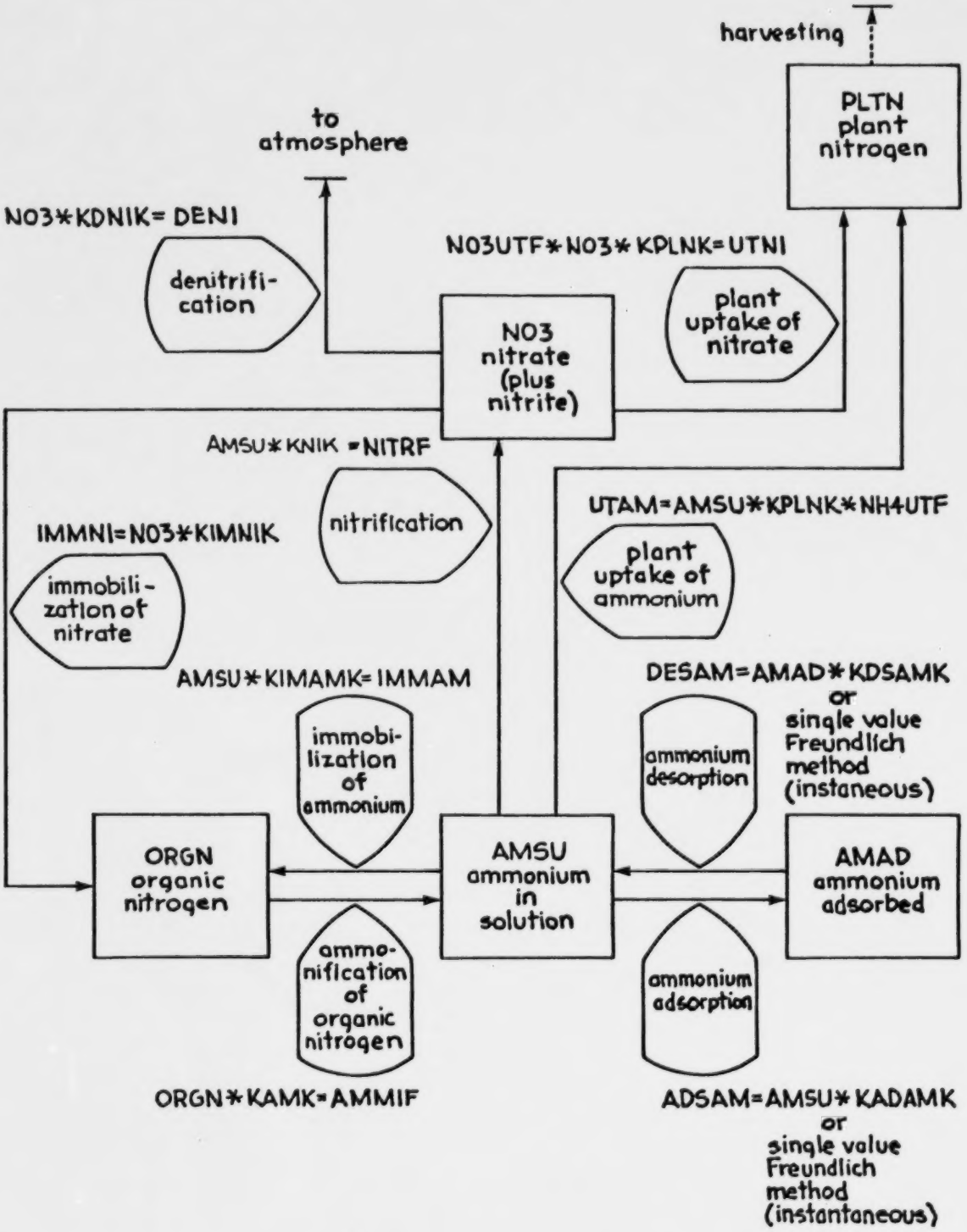


Figure 2.5 Flow diagram for nitrogen reactions

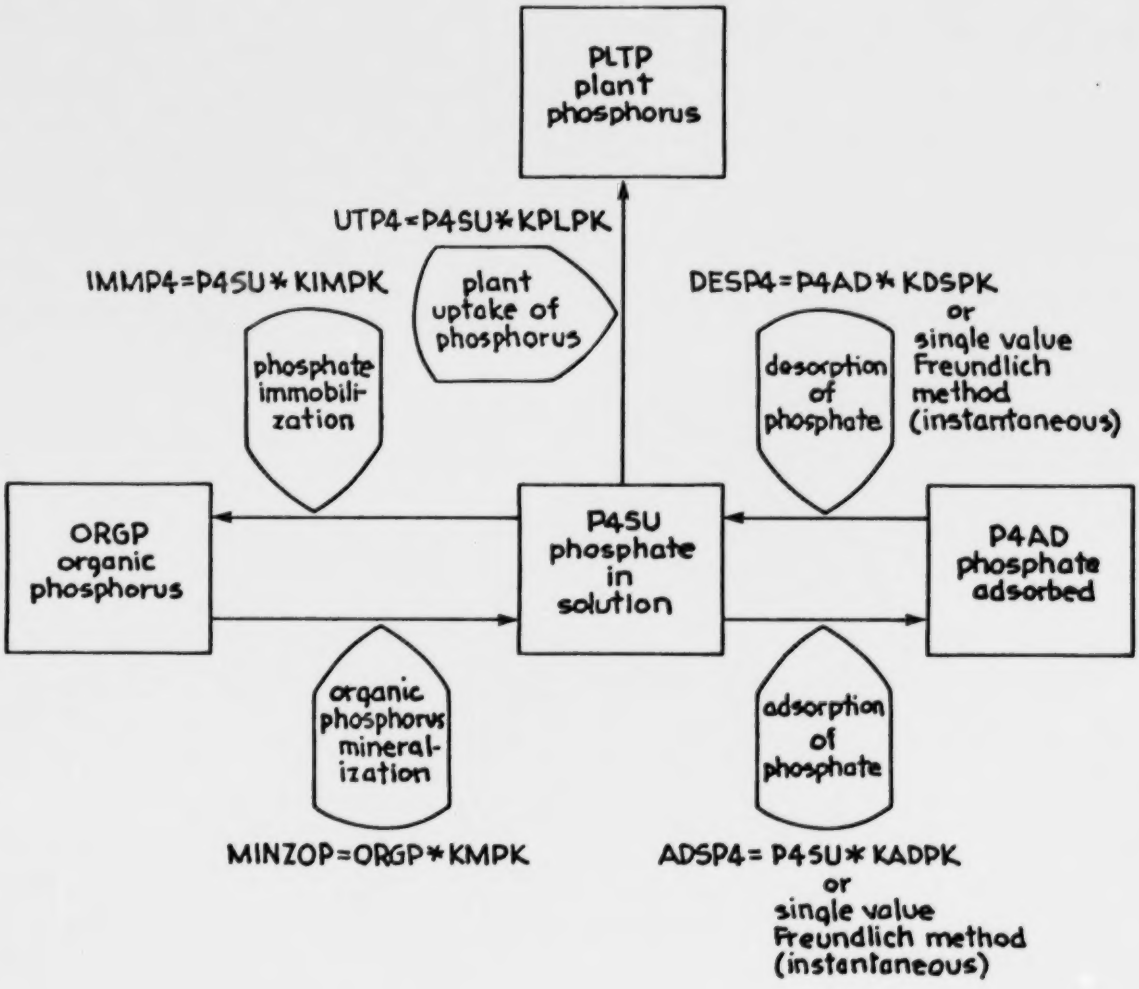


Figure 2.6 Flow diagram for phosphorus reactions

parameters are specified for each soil layer; thus variations in characteristics of the soil profile can be accommodated by varying the reaction rates for the different soil layers.

2.7 Differences between HSPF PERLND and the ARM II model

Although the hydrology, snow, sediment, and agri-chemical sections of HSPF PERLND were derived from the ARM II model, a number of differences exist primarily as additional capabilities and options in HSPF. The major additional options related to the representation of agricultural runoff processes and management practices are as follows:

a. Allowance of monthly variations for the upper zone soil moisture storage capacity (UZSN), Manning's 'n', and interflow volume (INTFW) and recession (IRC) parameters.

b. Specification of monthly rainfall interception (EPXM) separate from land cover. In ARM II, the monthly variation in land cover determined the relative changes in interception.

c. Adsorption/desorption of NH4, PO4, and pesticides by either Freundlich isotherms or first-order kinetics. ARM II included only first-order kinetics for NH4 and PO4, and only the Freundlich methods for pesticides.

d. Different pesticide parameter values for each soil layer.

e. Simulation of up to three pesticides in one model run.

f. A factor to reduce solute leaching from the surface layer. ARM II included factors only for the upper and lower soil layers.

g. Simulation of nitrogen and phosphorus processes separately and the use of different time steps for the chemical and biochemical transformations. The ARM II model required simulation of both nitrogen and phosphorus in each nutrient run and used the same time step for all transformations.

h. Plant uptake of NH4 as well as NO3.

i. Use of one to five areal source blocks to represent areal variation in hydrologic and sediment processes. The ARM II model included a fixed five block set-up.

j. Capability to adjust any state variable or parameter at any time during the simulation with the 'Special Actions' option in HSPF. This is the method used in HSPF to update sediment or chemical storages resulting from tillage operations and chemical applications respectively. However, it can also be used to adjust any parameter, such as infiltration or soil bulk density, or state variable to better represent the effects of specific tillage operations or practices.

One additional difference that is inherent in the basic structure of HSPF is the capability to have one pervious land segment tributary to another pervious land segment. A basic limitation of all HSPF predecessor models was that all land segments were tributary (or directly connected) to a stream channel. This new capability can allow for better representation of changing land slopes within a watershed, or the situation of a 'row crop' segment tributary to a 'grass waterway' or 'filter strip' segments. This capability expands the management alternatives that can be analyzed with HSPF.

The above differences between HSPF and the ARM II model attempt to correct previously recognized deficiencies in ARM II and provide the capabilities to more accurately reflect varying watershed and land surface conditions.

SECTION 3

METHODOLOGY FOR EVALUATING BMP IMPACTS

3.1 Introduction

Our approach to assessing the manner in which HSPF parameters should be adjusted to represent the effects of candidate BMPs involved the following steps:

a. Define conventional agricultural practices for Iowa watersheds.

b. Select and define candidate BMPs.

c. Evaluate qualitatively the impact of each candidate BMP on agricultural runoff processes (quantity and quality) relative to conventional practices.

d. Identify HSPF model parameters that control or affect specific runoff processes (quantity and quality).

e. Evaluate qualitatively the relative effect of each candidate BMP on the HSPF model parameters identified above.

f. Quantify the effects of the candidate BMPs on the identified model parameters based on available data, current literature, and, lacking all else, best judgment or experience.

Our intent was to follow a step-by-step procedure to define base conditions and candidate alternatives, and qualitatively assess the BMP effects on runoff processes and associated model parameters. These qualitative assessments then provided the basis for quantifying the changes in model parameters based on our best current knowledge. Through this process we established a common understanding among the project team members of the primary effects of each candidate BMP on runoff processes, and the relative direction of change on the processes and associated model parameters.

3.2 Conventional practices and candidate BMPs

The following definition of conventional agricultural practices for Iowa watersheds was established to provide a well-defined basis for comparing alternatives:

DEFINITION OF CONVENTIONAL AGRICULTURAL PRACTICES FOR IOWA WATERSHEDS

> "Conventional agricultural practices for Iowa are assumed to include continuous row-cropping (no close-grown crops in rotation) and moldboard plowing followed by secondary tillage at least once to smooth and pulverize the soil for planting, with cultivation when and where appropriate. Cropping and tillage operations are assumed to be straight row and usually parallel to field borders regardless of slope direction. Fertilizer application and moldboard plowing are assumed to be done in the fall, with disking and pesticide application in the spring prior to planting. In all cases with conventional tillage, the soil surface is free from residues for a period of time. One or two cultivation operations may be performed as needed during the early growing season."

It is recognized that crop rotation is occasionally used and that fertilizer application and plowing may be postponed until spring depending on weather conditions and farmer's schedules during the fall. The above definition includes the most probable components of conventional practices, and ones that will usually produce the largest sediment and pollutant loads. The primary components include moldboard plowing and secondary tillage for seedbed preparation, one or two cultivation operations during the early growing season, and crop residue removal following harvest in the fall. Thus, any change from conventional practices can be considered as a possible alternative.

Table 3.1 presents the list of candidate BMPs primarily related to row-crop agriculture considered in this study. This list was initially developed from previous work by Stewart et al., (1975), Haith and Loehr (1979), Walter et al., (1979), and Baker (1980), and was refined from information presented by Harman and Duncan (1978) and knowledge of local conditions in Iowa. Our working definitions of these candidate BMPs are included in the Appendix.

The list is divided into nonstructural, structural, and input management measures. The nonstructural measures include primarily cultural agronomic practices that affect farming methods and procedures to protect the land surface with residue or vegetal cover, reduce or retard surface runoff as a transport medium for pollutants, or increase infiltration and soil moisture storage to further reduce surface runoff. Nonstructural measures may require the use of new or different tillage equipment, and may require adjustments to chemical inputs in order to maintain productivity.

TABLE 3.1 CANDIDATE BEST MANAGEMENT PRACTICES

Nonstructural measures

1. No-tillage
2. Conservation tillage
   a. Till-planting
   b. Chisel plowing
   c. Disking
3. Contour farming
4. Graded rows
5. Contour strip cropping
6. Spring plowing
7. Sod-based rotation
8. Winter cover crop
9. Permanent meadow
10. Mechanical cultivation
11. Crop rotation

Structural measures

1. Terraces
2. Diversions
3. Grassed waterways
4. Filter strips
5. Tile drainage
6. Retention basins

Input Management Options

1. Improve soil fertility
2. Eliminate excess applications of nutrients or pesticides
3. Optimize timing of planting and chemical application
4. Controlling release and chemical transformation rates
5. Biological control
6. Incorporation of applied chemicals

Structural measures as listed in Table 3.1, require some construction on the watershed and continuing maintenance of the resulting structures such as terraces, retention/ sedimentation basins, grassed waterways, etc. As opposed to nonstructural measures that are essentially 'source-control' procedures preventing the generation of runoff, sediment, and pollutants, structural measures are 'treatment-type' methods that attempt to remove pollutants by deposition or sedimentation processes. Tile drainage is an exception to this since it uses the soil as a filtering medium as it decreases surface and increases subsurface flows.

Input management options relate to modifying the timing, amounts, form, and/or placement of chemical inputs of fertilizers and pesticides to reduce their availability for runoff or transport from the soil. The options involve reducing the need for chemicals by various means, or improving the coordination (timing) of chemical availability and plant requirements for fertilizers and pesticides.

3.3 Agricultural runoff processes/components and BMPs

The results of our qualitative assessment of the effects of the selected candidate BMPs on agricultural runoff processes and components are shown in Table 3.2. The processes and components listed across the top of the matrix in Table 3.2 have been separated into runoff, sediment, and chemical-related categories, with an 'other' category for soil temperature and bulk density. With the candidate BMPs listed in the left column, the matrix presents the relative effect of each BMP on each process. As noted in the legend, a '+' notation in the matrix indicates that the practice being considered increases or enhances a process with respect to conventional practices, a '-' notation indicates that a practice decreases or retards a process with respect to conventional practices, and a '0' denotes that the practice does not result in effects significantly different than those of conventional practices.

In some cases the relationships of a practice to a process is vague, or we do not have the technical information to provide a proper evaluation, in which case a '?' has been inserted. Where the specific implementation of a BMP will determine its effects, multiple notations are included in the associated boxes in Table 3.2.

From Table 3.2 the primary impacts of each BMP category on the runoff, sediment, and chemical processes can be analyzed qualitatively. Quite clearly, the nonstructural measures consistently reduce overland flow and increase infiltration and subsurface flow. Measures that include crop residues on the field or close-grown crops or meadow also increase rainfall

Table 3.2 Relative Impact of Selected BMP's on Agricultural Runoff Processes/Components Compared to Conventional Practices

MANAGEMENT PRACTICE	Runoff-Related: Interception	Depression/Surface Storage	Soil Moisture Storage	Overland Flow	Infiltration	Subsurface Flow	Evapo-transpiration	Snowmelt	Sediment-Related: Detachment by Rainfall	Detachment/Scour by Overland Flow	Transport by Overland Flow	Delivery to Stream	Gully Erosion/Scour	Availability/Production of Sediment Fines	Aggregation/Compaction	Chemical-Related: Availability/Input (Surface and Subsurface)	Transformations	Uptake/Degradation	Adsorption/Desorption	Other	Soil Temperature	Soil Bulk Density
Nonstructural Measures																						
1. No Tillage	+	0,+	0,+	−	+	+	−	+,0[7]	−	−	−	0	−	−	−	+[8]	0,−	0[7]	+[7]		−,+	+
2. Conservation Tillage	+	0,+	0,+	−	+	+	0	+,0[7]	−	−	−	0	−	−	−	+[8]	0,−	0	+[7]		−,+	+
3. Contour Farming	0	+	0	−	0	0,+	0	0	0	−	−	0	−	0	0	0	0	0	0		0	0
4. Graded Rows	0	0	0	−,+[1]	0	+,−[7]	0	0	0	−	−[7]	0	−	0	0	0	0	0	0		0	0
5. Contour Strip Cropping[2]	0	+	0	−	+	0,+	0	0	−,0	−	−	0	−	−,0	0	−	0	0	+[7]		0	0
6. Spring Plowing[3]	+	+,0	0	−	+,0	+	0	0	−	−	−	0	0,−	−,0	0[7]	0,+	+[7]	0	0		−,+	0
7. Sod-Based Rotation[4]	+	0,+	0,+	−	+	+[7]	+	0[7]	−	−	−	0	−	−	[7]	−	0	0	+[7]		0[7]	+[7]
8. Winter Crop Cover	+	0	0	−	+[7]	+	+,0	+	−	−	−	0	0,−	+,−	−,0	0,+	0	+	+[7]		0,+	0
9. Permanent Meadow	+	+	0,+	−	+	+[7]	+	+	−	−	−	0	−	−	−,+	−	0	+,−[7]	0		0,+	+[7]
10. Mechanical Cultivation	0	+	0	−	+	+	+	0	+	+	+	0	0	+	−	−	0	0	0		+	−
11. Crop Rotation	0	0	0	−	+	+	+	0	0	0	0	0	0	0	0	−	0	0	0		0	0
STRUCTURAL MEASURES																						
1 Terraces	0	+,0	0	−	+,0	0,+	0	0	0	−	0,−	−	−	0	0	0	0	0	0		0	0
2 Diversions	0	0	0	+	−[7]	−[7]	0	0	0	−	+[7]	−,+	−	0	0	0	0	0	0		0	0
3 Grassed Waterways[5]	0,+	0	0	−	+[7]	0	0	0	−	−	−	−	−	0	0	−	0	0	0[7]		0	0
4 Filter Strips[6]	0,+	0	0	−[7]	+[7]	0	0	0	−	−	−	−	−	0	0	−	0	0	0[7]		0	0
5 Tile Drainage	0	0	0	−	+	+	0	−,0	0	−,0	−,0	−	−	0	0	0	0	0	0		0	0
6 Retention Basins	0	0	0	0	0	0	0	0	0	0	0	−	−	0	0	0	0	0	0		0	0
INPUT MANAGEMENT OPTIONS																						
1 Improve Soil Fertility	+	[7]	[7]	−	+	[7]	+	0	−	−,0	−,0	0	−,0	0	−	0,+	0,+	0,+	0,+		0,−	−[7]
2 Eliminate Excessive Applications	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−	0	0	0		0	0
3 Optimize Timing of Planting and Chemical Applications	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−	0	+	0[7]		0	0
4 Control Release and Transformation Rates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−,0	+	+	[7]		0	0
5 Biological Control	[7]	0	0	0	0	0	[7]	0	[7]	0	0	0	0	[7]	[7]	−	0	[7]	0		0	0
6 Incorporation of Applied Chemicals By Tillage	0	+	0	−	+	[7]	+	0	+	+	+	0	0	+	−	−	0	0	+[7]		+	−

Footnotes to Management Practice Vs. Process Matrix

1. Many practices have effects which are time-dependent because they are applied in different seasons of the year. Comparisons indicate long term deviatiations from base conditions.
2. Processes are considered only within the strips of grass or close-growing crops growing between the cultivated crops.
3. The overall effects of shifting plowing from fall to spring are considered.
4. Processes are considered for the sod year only.
5. Processes are considered only within the grassed waterway.
6. Processes are considered only within the filter strip.
7. Crop residue catches drifting snow.
8. Decrease in incorporation of chemicals into the soil results in an increase in surface availability. Also, nutrient leaching from crop residues can increase nutrient availability.

LEGEND

+ = increases or enhances process with respect to conventional practices

− = decreases or retards process with respect to conventional practices

0 = does not result in effects significantly different than use of conventional practices

interception and surface depression storage. The runoff effects are also reflected in the sediment processes by reductions in the detachment/scour and transport of sediment by overland flow, detachment by rainfall, and gully erosion. The reduction in number and severity of tillage operations associated with the nonstructural measures is shown in the reduction of the availability or production of detached soil fines.

For the chemical-related processes, the nonstructural measures can lead to a reduced requirement for use of chemicals due to crop rotations, increased mechanical cultivation (in place of herbicide applications), and sod or meadow rotations. However, practices such as no tillage, conservation tillage, spring plowing or winter cover crops can actually increase chemical needs or provide additional nutrients leached from crop residues. The effects of nonstructural measures on other chemical processes are not as well-defined.

Structural measures primarily impact the runoff and sediment related processes. Their effects are concentrated on the outflow from the field or watershed, whereas nonstructural measures affect processes on the land surface and within the soil. Grassed waterways and filter strips are evaluated in terms of their effects on processes within the waterway or filter strip since these measures are applied to a small portion of the field or watershed. Structural measures generally lead to some reduction in overland flow with a corresponding increase in infiltration and subsurface flow, but their major impact is on the sediment detachment/ scour and transport by overland flow and sediment delivery from the field or watershed. Gully erosion and scour are also reduced by structural measures. Thus, these measures primarily reduce the pollutant transport mechanisms with their major effect on sediment-associated pollutants.

The input management options, as opposed to the structural measures, exert their primary effects on the chemical processes. The goal is to reduce the amount of chemical that can runoff by reducing chemical inputs, increasing the efficiency of applied chemicals, reducing the amounts on the land surface by incorporation, or modifying chemical release and transformation rates to keep the chemicals in their less mobile forms as long as possible. The specific effects of options such as controlling release and transformation rates and biological control depend on the specific chemicals and methods used, application procedures and chemical characteristics. Also, an input management practice that requires chemical incorporation by tillage will cause changes in runoff and sediment processes due to the additional tillage operation. Practices, such as improving soil fertility, that result in greater crop canopies and yields will cause attendant changes in interception,

detachment, infiltration, overland flow, and sediment transport due to the crop canopy, soil tilth, and residue effects.

3.4 BMPs and HSPF parameters

Table 3.3 presents our qualitative assessment of how the candidate BMPs could be represented by the indicated changes in HSPF parameters relative to those for conventional practices. The appendix provides a detailed comparison of the HSPF parameters in Table 3.3 with the corresponding ARM model parameters, with differences noted. Since the chemical parameters are defined for each nutrient form or pesticide, the parameters have been grouped in Table 3.3 by each major process or component (e.g., surface storage, adsorption/desorption). The sediment parameters are defined with the algorithm discussion in section 2.4, and the major runoff related parameters are defined below:

CEPSC - Interception storage capacity. Daily values are linearly interpolated from input monthly values.
UZSN - Nominal upper zone soil moisture storage capacity.
LZSN - Nominal lower zone soil moisture storage capacity.
LSUR - Average length of the overland flow path.
SLSUR - Average slope of the overland flow path.
NSUR - Manning's 'n' value for the overland flow path.
INFILT - Index to the infiltration capacity of the soil.
INTFW - Interflow volume parameter.
LZETP - Lower zone evapotranspiration parameter.
SNOWCF - Snow catch parameter to account for poor catch efficiency of gages.

The meaning of the symbols in Table 3.3 is analogous to those in Table 3.2; a '0' means no change in a parameter from its conventional practice, while a '+' or '-', means an increase or decrease, respectively, in a parameter with respect to conventional practices. As with Table 3.2, the qualitative assessment in Table 3.3 was based on our best current knowledge of the effects of a particular management practice in light of the process representations in HSPF and associated parameter definitions. The existence of question marks (?) in Table 3.3 indicates uncertainty in assessing the effects of a management practice - parameter combination. The areas of uncertainty are due to either a lack of knowledge of the real effects of a practice or insufficient information to generalize the effects of a practice. In many cases the BMPs need to be better defined

Relative Impact of Selected BMP's on HSPF Parameters

MANAGEMENT PRACTICE[1]	Runoff Related: CEPSC (M)	UZSN (M)	LSUR	SLSUR	NSUR (M)	INFILT	INTFW (M)	LZETP (M)	SNOWCF	Sediment Related: COVER (M)	KRER	SMPF	KSER	KGER	DETS - Tillage	AFFIX	Chemical Related: SPS - Surface Chemical	UPS - UpperZone Chemical	Nutrient Input Surface Layer	Nutrient Input UpperZone	Adsorption / Desorption	Biochemical Transformation Rates	Nutrient Uptake Rate by Plants (M)	Pesticide (M) Degradation Rate	Soil Related: Soil Temperature	Soil Depths	Bulk Density
Nonstructural Measures																											
1. No Tillage	+	+	0	0	+	+	0[7]	−	+[7]	+	−[8]	0	−	−	−	−[8]	+[8]	+[8]	+[8]	+	−[7]	0[7]	0[7]		−[4]	?	+
2. Conservation Tillage	+	+	0	0	+	+	0[7]	0	+[7]	+	−[8]	0	−	−	−	−[8]	+[8]	+	+	+	−[7]	0	0		−[4]	?	+
3. Contour Farming	0	+	0	0	0	0	+[7]	0	0	0	0	−	−0	−	0	0	0	0	0	0	0	0	0		0	0	0
4. Graded Rows	0	0	+	−	0	0	0	0	0	0	0	−	−	−	0	0	0	0	0	0	0	0	0		0	0	0
5. Contour Strip Cropping[2]	0	+	0	0	+[2]	+	+	0[2]	0	+,−	0	−	−	−	0	0	0	0	0	0	0	0	0		0	0	0
6. Spring Plowing[3]	+	+	0	0	−[3]	−[3]	+	0	0[3]	+	0	0	0−	0−	0	?	0	0	0	0	0	0	0		−[4]	0	0
7. Sod-Based Rotation[4]	+,−	+	0	0	+	+	0[7]	+	0	+	−	0	−	−	−	?	0	0	0	0	0	0	0		−	0	0
8. Winter Crop Cover	+	0,+	0	0	+	+	0	0	+	+	−[8]	0	−	−	0[4]	0[7]	−	−	−	−	+[8]	0	−	?	0	?	+
9. Permanent Meadow	+,−	+	0	0	+	+	0	+	+	+	−[8]	0	−	−	0	?	0	0	+	+	+[8]	0	+	?	0	0	0
10. Mechanical Cultivation	0	+	0	0	+	+	+	+,0	0	+	−[8]	0	−	−	−?	0	−	−	−	−	0[7]	0	+[8]	?	−,+	?	+
11. Crop Rotation	+,−	0	0	0	0	0	0	−,+	0	0	+,0	0	+,0	0	+	+,0	−	−	0	0	0[7]	+,−	0	?	+[7]	?	−?
										+,−	0	−0	0[7]	0	0	0	0	0	0	0	0	0	0		0	0	0
Structural Measures																											
1. Terraces	0	+	+	0	0	+	+	0	0	0	0	−	0−	−	0	0	0	0	0	0	0	0	0		0	0	0
2. Diversions	0	0	+	0	0	−	0	0	0	0	0	0	0−	−	0	0	0	0	0	0	0	0	0		0	0	0
3. Grassed Waterways[5]	−,0	+	0	0	+	+	0	0	0	+,−	−	0	−	−	−	0	0	−	−	−	0[7]	0	0[7]	0	0[4]	0[7]	+[7]
4. Filter Strips[6]	−,0	+	0	0	0	+	+	0	0	+,−	−	0	−	−	−	0	−	−	−	−	0[7]	0	0[7]	0	0[4]	0[7]	+[7]
5. Tile Drainage	0	0	0	0	0	+	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+[7]	0	0	0	0	0
6. Retention Basins	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Input Management Options																											
1. Improve Soil Fertility	+	+	0	0	0	+	−[8]	+,0	+,[7]	+,0	−0	0	0	0	0	0	0	0	0,−	0	+[7]	+	+	0[7]	0	0	?
2. Eliminate Excessive Applications	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−	−	−	−	0	0	0	0	0	0	0
3. Optimize Timing of Planting and Chemical Applications	0	0	0	0	0	0	0	0	0	+	−	0	0	0	0	0	−	−	−	−	0	0	+[7]	0	0	0	0
4. Control Release and Transformation Rates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	−	−	0	+−	+,−	?	0	0	0
5. Biological Control	0	0	0	0	0	0	0	+[7]	0	0	−[8]	0	0	0	0	0	−	−	0	0	0	0	0	0	+?	?	−?
6. Incorporate Applied Chemicals	0	+	0	0	+	+	+	+	0	0	+[8]	0	+	0	+	+0	−	+	−	+	0[7]	+,[7]	+	+	+−		

Footnotes to Management Practice Vs. HSPF Parameter Matrix

1. Many practices have effects which are time-dependent because they are applied in different seasons of the year. Comparisons indicate overall long term deviations from base conditions.
2. Parameter changes are considered only within the strips of grass or close-growing crops growing between the cultivated crops.
3. The overall effects of shifting plowing from fall to spring are considered.
4. Parameter changes are considered for the sod year only.
5. Parameter changes are considered only within the grassed waterway.
6. Parameter changes are considered only within the filter strips.
7. Crop residues catch drifting snow which can be represented by increasing SNOWCF.
8. Decrease in incorporation of chemicals into the soil results in an increase in surface availability. Also, nutrient leaching from crop residues can increase nutrient availability from the base condition.

LEGEND

+ = increases parameter with respect to conventional practices

− = decreases parameter with respect to conventional practices

0 = does not result in effects significantly different than those of conventional practices.

in terms of their implementation under local conditions before their impact can be assessed.

Table 3.3 provided the guidance for evaluating parameter values and developing evaluation guidelines for analyzing parameter changes for BMPs in Iowa. The boxes with nonzero entries in Table 3.3 indicate the management practice-parameter combinations discussed in Section 4.

SECTION 4

HSPF PARAMETER GUIDELINES AND VALUES FOR BMPs IN IOWA

4.1 Introduction

This section discusses the major HSPF runoff, sediment and chemical parameters in terms of adjustments or changes needed to simulate the effects of the candidate BMPs. The information provided supplements and expands upon the parameter evaluation guidelines given in the ARM Model User's Manual (Donigian and Davis, 1978).

In order to accurately assess and model the effects of management practices, data should be collected from instrumented watersheds under a variety of different practices. Since a wide range of meteorologic, topographic, and soil conditions would need to be analyzed through costly sampling and laboratory analysis programs, the best current alternative is to relate HSPF parameters to relevant data available from the current literature including information from other modeling procedures. For the physically-based parameters, relationships are relatively well-defined and evaluation is limited by the extent and veracity of the research that has been performed on the associated effects of BMPs.

For the calibration-dependent parameters, i.e. those that must be adjusted as a result of comparing simulated and observed information, an additional limitation exists in defining the proper relationship of HSPF parameters to parameters from other modeling procedures (e.g. SCS Curve Numbers, USLE) which have published values related to different practices. Uncertainty still exists with regard to how well the parameters from these other modeling procedures can represent the effects of candidate BMPs, since the data supporting the parameter relationships are not often cited.

The following sections discuss both physically-based and calibration-dependent parameters for the runoff, sediment, and chemical processes simulated by HSPF PERLND. Procedures and guidelines are presented and specific values are developed for the local conditions on the Four Mile Creek watershed, Tama County, Iowa. The HSPF parameter names are used with the ARM model parameter name in parentheses if a different name is used in the ARM model.

4.2 HSPF runoff parameters

As discussed in Section 2.3, the HSPF PWATER section and its predecessors HSP and ARM are based on the Stanford Watershed Model. Although the Stanford model has been used successfully in many drainage basins, applications to field-size (1-50 ha) agricultural catchments have not been extensive. The hydrologic portion of HSPF contains many parameters, some of which are usually determined by calibration with observed runoff data. The purpose of this section is to outline general methodologies for estimating the runoff parameters noted in Section 3.0 which are likely to change with different practices, and to provide the specific values for BMPs in the Four Mile Creek watershed, Tama County, Iowa.

The specific examples given are based on a Tama Silty Clay Loam (Typic Argiudoll) with the following properties:

a. Bulk density,

depth (cm)	0-1	1-7.5	7.5-45
bulk density (g/cc)	1.0	1.3	1.4

b. Wilting Point (Soil Survey Staff, 1975, p. 660)

Horizon	Ap	A12	A3
Depth (cm)	0-18	18-28	28-43
Wilting Point (% by wt.)	12.7	13.6	14.4

The soil is classified in hydrologic group B with a moderate infiltration rate.

CEPSC (EPXM) - Maximum interception storage.

There are basically three types of land surfaces related to interception: bare soil, residues on the soil, and a growing crop. Obviously, the first two conditions demonstrate significantly less interception than a growing crop canopy which accounts for the majority of rainfall interception occurring on croplands. During crop periods, CEPSC is governed by the rate of canopy development. In the ARM User's Manual, maximum cropland interception values of 0.1- 0.25 in. are given, and based on other reviews (Woolhiser, 1976), these values seem reasonable. The value of CEPSC should vary during the growing season, however, and a general equation for CEPSC (in.) as a function of time, 't' is

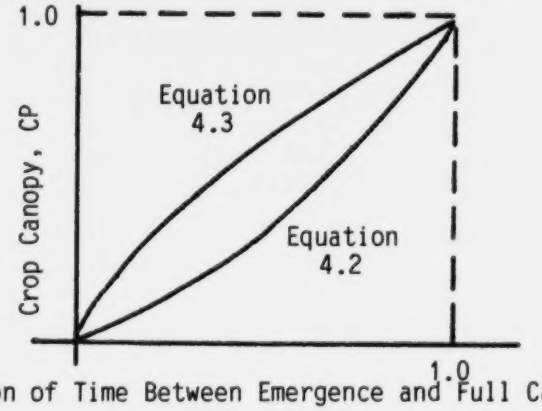
$$CEPSC(t) = IMAX * CP(t) \qquad (4.1)$$

where IMAX is the maximum (full canopy) interception (in.) and CP(t) is the fraction of soil surface covered by crop canopy at time t. Canopy development can be described by the equations:

$$CP(t) = 0.5*L(t)/(1.5 - L(t)) \quad (4.2)$$
$$CP(t) = 1.5*L(t)/(0.5 + L(t)) \quad (4.3)$$

where L(t) is the fraction of the time period between emergence and full canopy which has elapsed on day t. For row crops, emergence is approximately 7-10 days after planting and full canopy follows emergence by 6-8 weeks. After harvest, CP(t) drops back to zero. As shown in Figure 4.1, equation 4.2 applies to a crop with slow initial canopy development and equation 4.3 is suitable for crops with rapid initial development. It appears that most crops are better described by equation 4.2.

Figure 4.1
Crop Canopy Development Functions



The value of IMAX should in principle vary with crop type, although data is lacking to provide more than approximate indications of the variation. Lull (1964) gives total growing season interception for four crops: alfalfa - 3.87 in, corn - 1.10 in, soybeans - 0.91 in, oats - 0.47 in. The values of IMAX may show roughly this variation. Keeping within the range of 0.10-0.25 in, the following values are proposed for the four crops:

Crop	IMAX(in.)
Alfalfa	0.25
Corn	0.15
Soybeans	0.15
Oats	0.10

This procedure provides a simple means of describing a time variation in CEPSC. Note that once established, a sod crop (alfalfa) will have CP(t) = 1, and CEPSC(t) = 0.25 until plowing.

Compared with a growing crop canopy, bare fallow soil and crop residues will demonstrate small interception capacities. However, with the possibility that up to 80-90% of the land surface can be covered by crop residues of 3000 to 5000 pounds/acre (Wischmeier and Smith, 1978), it is clear that non-zero values for CEPSC should be used for periods when crop residues remain on the field. Although there exists very little data on rainfall interception by crop residues, previous applications of the ARM model have used CEPSC values of 0.06 to 0.12 inches for periods when crop residues exist. Dividing this range by the 3000 to 5000 pounds/acre range of crop residues suggests interception values of 0.020 to 0.025 inches per 1000 pounds/acre of crop residue. These values can be used to estimate CEPSC values for crop residues until more data and research becomes available.

The final surface condition of bare fallow soil has minimal interception capacity, but non-zero values for CEPSC in the range of 0.01 to 0.03 inches have been used in past applications. This can be attributed to fringe areas of a field or remaining residue even after plowing.

Siemens and Oschwald (1978) and Laflen (1980) have presented data showing the variation in crop residue amounts on the land surface under different tillage and conservation tillage systems. Their data show that crop residue amounts and coverage are reduced between harvest in the fall and planting in the spring, presumably due to breakdown and deterioration of the residue. Corn and soybean residues were reduced 10% and 30%, respectively, over a period from November to April. Under no-till systems, crop residue cover after planting in the spring can be 50-70% for corn residue and 20-40% for soybean residue (Laflen, 1980); soybean residues undergo faster deterioration. Also, some portion of the previous years residue existed at the time of full crop canopy and subsequent harvest (Siemens and Oschwald, 1978). Thus, accurate representation of conservation tillage systems should include the joint interception by crop residues and a growing crop canopy, and the time variation of crop residue amounts as affected by tillage operations, harvest, and residue deterioration.

Table 4.1 from Rawls et al.(1980) presents an approximate method of estimating residue amounts resulting from different crops given the crop yield, while Table 4.2 (Rawls et al., 1980) provides residue reduction factors for various tillage operations. These factors are in rough agreement with the data from Siemens and Oschwald (1978) and Laflen (1980), with the condition that soybean residues are reduced 2 to 3 times faster than corn residues under the same tillage operation. These tables can be used to estimate crop residue amounts and reductions by tillage operations as a basis for defining the

TABLE 4.1--METHOD FOR CONVERTING CROP YIELDS TO RESIDUE *

Crop	Straw/grain ratio	Bushel weight (kg)	Bushel weight (lb)
Barley	1.5	21.8	48
Corn	1.0	25.4	56
Oats	2.0	14.5	32
Rice	1.5	20.4	45
Rye	1.5	25.4	56
Sorghum	1.0	25.4	56
Soybeans	1.5	27.2	60
Winter wheat	1.7	27.2	60
Spring wheat	1.3	27.2	60

* - Crop residue in lb/acre = (straw/grain ratio) x (bushel weight in lb) x (crop yield in bu/acre).

TABLE 4.2--RESIDUE REDUCTION FROM TILLAGE OPERATIONS

Tillage operation	Residue reduction (%)
Chisel plow	35
Rod weeder	10
Light disk	30
Heavy disk	70
Moldboard plow	90
Till plant	20
Fluted coulter	10
V sweep	10

Source: Rawls et al., 1980

variations in crop residues on the land surface over the year; reduction by deterioration over a winter period can be estimated as 10 to 30% unless other data is available. Using factors of 0.02 to 0.025 inches per 1000 pounds/acre, interception values for crop residues can be estimated.

Since HSPF allows the input of monthly CEPSC values, the annual variation in crop canopy and crop residues need to be defined, converted to interception values, and summed to obtain the total CEPSC values on a monthly basis (as of the first day of each month) for each candidate BMP. Clearly, BMPs that result in changes in the type or timing of the crop canopy or crop residue on the land surface will require modifications to the CEPSC values as described above.

UZSN - Nominal Upper Zone Soil Moisture Storage Capacity

This parameter is a nominal measurement of depression storage and initial "pore storage" in the near-surface zone. Its importance in the model is as a determinant of the portion P of the surface water which is retained in the upper zone. P is approximately 1.0 for UZS/UZSN less than or equal to 1.0, and P is approximately 0.0 for UZS/UZSN greater than or equal to 3.0. The parameter, along with INFILT, exerts a major effect on surface runoff.

The initial abstraction term I in the SCS Curve Number (CN) equation is related in concept to UZSN. In the CN equation I represents the water taken up by interception, depression storage and infiltration into the surface soil. As such it is the maximum storage of the various surface processes, whereas UZSN is primarily a function of soil and surface condition. In HSPF, infiltration is represented as the net amount of water reaching the lower zone. If we assume that the CN initial abstraction includes negligible water movement below the surface, then since the maximum capacity of HSPF's upper zone is 3UZSN,

$$3*UZSN + CEPSC(t) = I \qquad (4.4)$$

Since I changes with antecedent moisture condition (AMC), its maximum value is I1, the initial abstraction at AMC1, the driest soil moisture condition. Thus,

$$UZSN = (I1 - CEPSC(t))/3 \qquad (4.5)$$

For example, with a corn crop on Tama soil, poor hydrologic condition at full canopy, we get the following values:

	CN2	CN1	I1(in)	UZSN(in)
Straight Row:	81	64	1.12	0.32
Contouring:	79	62	1.23	0.36

These values are for CEPSC(t) = 0.15 in. Values of CN2 and CN1, the curve numvers for AMC2 and AMC1, and the AMC1 abstraction (I1) are from Ogrosky and Mockus (1964) or Stewart et al. (1976).

This procedure builds in two types of time variations. The first is with seasonal changes in CN and the second is related to CEPSC(t). However, for the Tama soil (hydrologic group B), I1 will always be much greater than CEPSC(t), and we can approximate UZSN as

$$UZSN = I1/3 \qquad (4.6)$$

Table 4.3 gives UZSN values predicted by equation 4.6 for selected BMPs. Curve numbers were obtained from Stewart et al. (1976), Appendix B. The following conditions apply to the table:

a) Except for sod, winter cover and meadow, all values are for row crops. Similar values can be derived for small grains.
b) Fallow period extends from plowing to two weeks after crop emergence. Hence a major effect of no tillage, conservation tillage and spring plowing is to reduce or eliminate the fallow period.
c) Curve numbers for winter cover are for the winter period only. Growing season values should correspond to conservation tillage.
d) Conventional, contour, graded rows, contour strip, spring plow and terraces are all "poor" hydrologic condition. The remaining practices increase soil organic matter and are "good" hydrologic condition.
e) Contour strip and graded rows are assumed to be similar to contour.

During the dormant season, values of UZSN may change depending on plowing. Fallow values should be used after moldboard plowing until 10% canopy development (approximately two weeks after emergence). Hence fall plowing will significantly reduce the dormant season values of UZSN.

Although it is clear that UZSN and the CN Initial Abstraction term are not identical concepts, the above procedures that define a relationship between them are the best that can be developed at the present time. The values in Table 4.3 should be used as a general guide. Monthly values for UZSN should be

TABLE 4.3 VALUES OF UZSN FOR SELECTED BMPS ON TAMA SILTY CLAY LOAM

Practice	CN2	CN1	I1 (in.)	UZSN=I1/3 (in.)
Fallow	86	72	0.78	0.26
Conventional	81	64	1.12	0.37
No Tillage	78	60	1.33	0.44
Conservative Tillage	78	60	1.33	0.44
Contour	79	62	1.23	0.41
Graded Rows	79	62	1.23	0.41
Contour Strip	79	62	1.23	0.41
Spring Plow	81	64	1.12	0.37
Sod Rotation				
Sod Year	72	53	1.77	0.59
Row Crop Year	78	60	1.33	0.44
Winter Cover (small grains)	75	57	1.51	0.50
Meadow	58	38	3.26	1.09
Terraces	74	55	1.64	0.55

calculated for each candidate BMP based on the expected monthly variations in interception (CEPSC) and land surface conditions, and using Equation 4.5 and CN procedures as discussed above. Alternately, values for UZSN calibrated for conventional practices (or some other base condition) can be adjusted for candidate BMPs in proportion to relative changes in I noted in Table 4.3, or more appropriately, from values derived for the specific soils and watershed conditions. This method has been employed in a previous use of the ARM model for evaluating agricultural practices (Beyerlein and Donigian, 1979).

LZSN - Nominal Lower Zone Soil Moisture Storage Capacity

This nominal storage capacity of the lower zone is essentially the available water capacity (AWC) of the root zone. Assuming a four-foot root zone, we have three independent estimates for the Tama soil:

a) ARM User's Manual, p. 56: 7 in.
b) Harmon and Duncan (1978), p. 92: 9.48 in.
c) Stewart et al. (1976), p. 133: 8 in.

LZSN = 8 inches seems like a reasonable compromise. Subject to adjustment through calibration, LZSN could be made to vary with time and crop since different crops have different root depths; the root zone depth could be modeled as in Stewart et al. (1976), Appendix B, to give changes in lower zone storage during the growing season. However, the primary effects of BMPs are on surface related processes and the effects, if any, averaged over the subsurface root zone would be an unnecessary and minimal refinement. HSPF uses a constant value for LZSN. For these reasons LZSN is not adjusted for BMPs.

LSUR(L), SLSUR(SS) - Length and slope of the overland flow path

The length (LSUR) and slope (SLSUR) of the overland flow path are catchment parameters which must be determined by a combination of topographic and practice characteristics. When HSPF is applied to a large catchment, the parameters are either averaged for the entire catchment or the catchment is divided into segments with uniform LSUR and SLSUR values. A variety of averaging approaches is available, some of which have been evaluated by Williams and Berndt (1977) for the length-slope factor of the Universal Soil Loss Equation.

Ree et al. (1977) discuss procedures of geomorphology to follow in estimating LSUR and SLSUR from topographic maps. For the average slope value, they recommend dividing the watershed area by the product of the sum of the lengths of the contours and the contour interval. For the average overland flow length, they use the procedure recommended in the ARM User's Manual, i.e.

dividing the watershed area by twice the total length of all drainageways. In this calculation, they emphasize the importance of determining the length of drainageways; they suggest that all drainageways on the topographic map be extended through the last contour indicating a draw or valley.

Candidate BMPs that modify the LSUR or SLSUR values, such as graded rows, terraces, diversions, tile drainage, need to be carefully described in terms of implementation on the watershed. BMPs that modify the overland flow path so that it is no longer uniform throughout its length may need to be analyzed as two separate tributary land segments as discussed in Section 2.7 and Section 4.5.

NSUR(NN) - Manning's 'n' for the overland flow path.

This parameter is the Manning's 'n' value which is the surface roughness factor used in the overland flow equation. Virtually all currently published values are for channel flow, and there is some uncertainty related to the applicability of the concept for very shallow overland flow where roughness is comparable to the depth of flow. Using observed hydrographs and averaged length and slope values for watersheds in Oklahoma, Ree et al. (1977) calculated NSUR values of 0.25 to 0.62 for a range of grass cover conditions. Using finite element methods of modeling overland flow, Ross et al. (1977) used an NSUR value of 0.30 for forested areas and 0.35 to 0.40 for agricultural areas in Virginia. Both of these studies indicate higher NSUR values than previously recommended in the ARM User's Manual. Our current best recommendations for NSUR values, subject to revision by additional data and research are as follows:

Conventional practices	0.15 - 0.25
Smooth fallow	0.15 - 0.20
Rough fallow, cultivated	0.20 - 0.30
Crop residues, light turf	0.25 - 0.35
Meadow, heavy turf	0.30 - 0.40

As with CEPSC and UZSN, NSUR values should be input with a monthly variation during the year reflecting the variation in surface roughness as a result of crop seasons and practices.

INFILT(INFIL) - Index to infiltration capacity of the soil.

The HSPF model calculates the average infiltration rate f (in./hr) to the lower zone storage (LZS) as

$$f = INFILT/(LZS/LZSN)^{**}2 \qquad (4.7)$$

Calibration is used to estimate INFILT, which is the value of f when LZS = LZSN. Since LZS only occasionally exceeds LZSN,

INFILT is often a lower bound on actual averaged infiltration rates. Calibrated values of INFILT are generally between 0.05 and 1.0, but typically are less than 0.2. Since equation 4.7 has not been commonly applied to agricultural field studies, it must be related to other infiltration models which have parameters with quantitative relationships to BMPs.

Holtan's infiltration equation (Holtan et al., 1975) can be used to estimate an upper bound on INFILT. Holtan's equation for infiltration rate f(in./hr) is

$$f = a*(Sc - S)**1.4 + fc \qquad (4.8)$$

In this equation, 'a' is a vegetative parameter described as follows (Holtan et al., 1975):

> ...the fraction of the ground-surface area occupied by plant stems or root crowns (at plant maturity). Stems and root crowns are assumed to reflect the fraction of porosity in the top layer that is surface connected by mature plant roots to form conduits for air or water.

Values of 'a' are listed in Table 4.4

The other variables in equation 4.8 are

Sc = soil water capacity in excess of wilting point (porosity - wilting point, in.)
S = soil water in excess of wilting point (in.)
fc = minimum infiltration rate after prolonged wetting (in./hr)

Equation 4.8 can be used to estimate infiltration as a function of cover and soil parameters, a and fc. Tillage effects may be modeled by their impact on bulk density and hence porosity. Thus, immediately after cultivation Sc in equation 4.8 should increase. Holtan's equation can be written in a more general form as

$$f = (a*d**1.4)*(Sc - s)**1.4 + fc \qquad (4.9)$$

where Sc and s are volumetric moisture capacity and content above wilting point (in./in.) and d is depth of the A horizon.

Comparison of HSPF and Holtan Equations

Although the coefficients of equations 4.7 and 4.9 are not directly comparable, they can be related assuming a relationship between the two soil moisture storage variables LZS and s. When

TABLE 4.4 VALUES OF 'a' FOR EQUATION (4.8)
(from Holtan et al., 1975)

Cover	'a' (in./hr per in.**1.4 of available storage) Poor Condition	Good Condition
Fallow	0.10	0.30
Row crops	0.10	0.20
Small grains	0.20	0.30
Hay		
Legumes	0.20	0.40
Sod	0.40	0.60
Pasture		
Bunchgrass	0.20	0.40
Temporary (sod)	0.40	0.60
Permanent (sod)	0.80	1.00
Woods and forests	0.80	1.00

the A horizon is at field capacity, s = AWC (available water capacity, in.) and

$$Fc = a*d**1.4(s - AWC)1.4 + fc \quad (4.10)$$

where Fc is the infiltration rate at field capacity. Equating this to the HSPF infiltration equation, we obtain

$$INFILT = Fc*(LZS/LZSN)**2 \quad (4.11)$$

If we know the moisture content in the lower zone when the A horizon is at field capacity, then equation 4.11 can be used to determine INFILT as functions of the known parameters a, d, s, AWC and Fc. The simplest assumption is that the lower zone is also at field capacity, and hence LZS = LZSN and INFILT = Fc, resulting in

$$INFILT = (a*d**1.4)*(s - AWC)**1.4 + fc \quad (4.12)$$

Given the structure of the HSPF model it is unlikely that LZS would exceed LZSN when s = AWC, but it does seem possible that LZS could be less than field capacity. Equation 4.11 is unfortunately very sensitive to LZS/LZSN. If LZS is only 1/2 of LZSN when s = AWC, then INFILT = 0.25*Fc. It appears that the most that can be said is that the values of INFILT obtained from equation 4.12 are probably upper bound estimates. The actual values of INFILT could be much lower than those predicted by equation 4.12.

INFILT Parameter Values for Tama Silty Clay Loam

This soil has a 17-in. (43-cm) A horizon (d= 17 in.) and, based on the values given in the beginning of this section, average values of bulk density (BD) and wilting point (W) for the horizon are 1.38 g/cc, and 0.22 in./in., respectively. Assuming a particle density of PD = 2.6 g/cc, the porosity N is

$$N = 1 - BD/PD \quad (4.13)$$
$$= 0.47 \text{ in./in.}$$

Soil moisture capacity is

$$s = N - W \quad (4.14)$$
$$= 0.25 \text{ in./in.}$$

The available water capacity is AWC = 0.21 in./in. (Harmon and Duncan, 1978).

The minimum infiltration rate fc depends on soil structure, and in particular the effects of previous cropping on soil organic matter. Musgrave and Holtan (1964) place Tama in a soil

category with fc in the range of 0.15 to 0.30 in./hr for 'clean-tilled' crops. They also provide data showing that in the last hour of a five-hour, 1.8 in./hr simulated rainfall, the measured infiltration rates for bluegrass and corn on Tama were 0.77 and 0.14 in./hr, respectively. It appears that fc = 0.15 in./hr is a reasonable base value for land with a row crop history.

Substituting the above parameter values into equation 4.12, the upper bound for INFILT is

INFILT = 0.58*a + 0.15 (4.15)

A comparable estimate can be obtained for the period immediately following tillage. Assuming that tillage temporarily lowers the BD of the top six inches of soil to 1.0 g/cc, the average BD of the A horizon is reduced to 1.26 g/cc. From equation 4.13, N would increase to 0.52 in./in. Assuming W and AMC are not changed by tillage, s would increase to 0.30 in./in. Substituting this value of s and AWC = 0.21 in./in. into equation 4.12 gives the following upper bound for INFILT immediately after tillage:

INFILT = 1.81*a + 0.15 (4.16)

Table 4.5 lists upper bounds for INFILT estimated by equations 4.15 and 4.16. The same conditions apply to this table as were noted for Table 4.3. The time variation is built into INFILT by the changes from fallow to crop periods and back.

Although the procedures described above are a reasonable development of the possible relationship between INFILT and Holtan's equation, the resulting INFILT values in Table 4.5 are 2 to 3 times greater than calibrated values obtained in previous model applications. The differences are likely due to the areal variation function for infiltration in HSPF and the impact of the upper zone on retaining and losing moisture through evapotranspiration. In effect, INFILT is a mean or average infiltration rate that produces the proper distribution of precipitation between surface and subsurface components. Under current conditions, calibration of INFILT to a base condition in Table 4.5 and then adjusting the calibrated value by the relative changes in Table 4.5 for different practices is the best that can be done at this time. The relative changes in INFILT shown in Table 4.5 for before and after tillage are in agreement with the calibration results for these periods from the Four Mile Creek HSPF application (Donigian et al, 1981).

INTFW(INTER) - Interflow volume parameter

This calibration parameter divides the non-infiltrating water into interflow and surface detention or runoff. In general,

TABLE 4.5 UPPER BOUND ESTIMATES OF INFILT FOR SELECTED BMPS ON TAMA SILTY CLAY LOAM

Practice	a	Upper Bound for INFILT (in./hr) Before Tillage (Equation 4.15)	Immediately After Tillage (Equation 4.16)
Conventional	0.10	0.21	0.33
Fallow	0.10	0.21	0.33
No Tillage	0.20	0.27	--
Conservative tillage	0.20	0.27	0.51
Contour	0.10	0.21	0.33
Graded rows	0.10	0.21	0.33
Contour strip	0.10	0.21	0.33
Spring plow	0.10	0.21	0.33
Sod rotation			
sod year (legume)	0.40	0.38	--
row crop year	0.20	0.27	0.51
Winter cover	0.30	0.32	--
Meadow (permanent sod)	1.00	0.73	--
Terraces	0.10	0.21	0.33

there appears to be no a priori way of estimating INTFW except from the guidelines presented in the ARM User's Manual based on previous experience. However, in deep soils such as Tama which do not have drainage restricted by low permeability layers, interflow is not likely to be a significant hydrologic component. Within the structure of the HSPF model, INTFW values less than 0.7 to 1.0 will usually produce interflow as 10 to 20% of total runoff depending on soil moisture conditions and the other hydrologic parameters. However, interflow can be significant as a subsurface transport medium for soluble pollutants, and any practice that decreases overland flow and increases subsurface flow will increase the amount of interflow, even without changes in the INTFW parameter. This results from the dependence of interflow on soil moisture conditions which is considered in HSPF. Because of this internal linkage and the uncertainties in estimating INTFW parameter, we recommend using the calibrated INTFW value for all management practices.

LZETP(K3) - Lower zone evapotranspiration parameter

This parameter adjusts the evapotranspiration (ET) from the lower zone to a fraction of the remaining potential evapotranspiration (PET) based on soil moisture conditions represented by the LZS/LZSN ratio. In HSPF, actual ET is calculated as a function of soil moisture conditions and input PET values. The total PET demand is first exerted on interception storage and any remaining demand is then exerted on the upper zone storage as a function of the UZS/UZSN ratio. After the interception and upper zone ET demands have been satisfied, any remaining PET is then exerted on the lower zone with the actual lower zone ET controlled by the LZETP parameter.

In principle, the LZETP parameter should be related to the fraction of the soil surface covered by crop canopy. In fact, the recommended guidelines included in the ARM User's Manual and all versions of the Stanford Watershed Model, suggest estimating LZETP as the fraction of the watershed covered by forest or deep-rooted vegetation. This implies a range of 0.0 to 1.0 for LZETP values, whereas in practice values of 0.20 to 0.90 are commonly used. In limited applications of the ARM model on agricultural watersheds, values of 0.20 to 0.25 have been used for fallow or areas without a growing crop (or during winter periods), and maximum values of 0.60 to 0.90 for complete transpiring crop canopies; the maximum is usually adjusted for the relative ET characteristics of different crops. Initial values are sometimes adjusted in calibration to refine the ET component of the annual water balance.

Clearly, the lower zone ET function in HSPF is empirical and appears to be unrelated to other commonly used ET models. The functions were originally developed and have been used

successfully on many natural (non-agricultural) watersheds as part of the continuous water balance calculations in the model. At present there is no definitive way of estimating LZETP for different practices other than the guidelines and experience noted above. Informed users should adjust LZETP, which is input on a monthly basis, to reflect changes in crops and cover conditions based on the relative time-varying ET characteristics of different crops. However, LZETP adjustments should be done judiciously and conservatively, and the simulation results should be carefully evaluated so that the effects of a candidate BMP are not distorted by adjustments to this parameter. Future modifications of HSPF should consider refining the lower zone ET function to a more rational and physically-based form appropriate for agricultural watersheds.

4.3 HSPF Sediment parameters

The selection process of BMPs for sediment control must take into consideration the particular sediment-related problem of concern. Sediment can accumulate over long periods of time reducing stream and lake capacities, it can occur in streams in high concentration reducing light penetration or clogging the gills of fish, or it can be the transport medium of adsorbed substances such as certain pesticides or nutrient forms. The source and character of the eroded sediment is a major determinant of the specific sediment-related pollution problems that exist. BMPs should be analyzed and selected to emphasize control of the critical source or size fraction of the sediment causing the water pollution.

Sediment is a product of the soil erosion process. This process begins on land with raindrops detaching surface soil granules. Sheet erosion is the removal of these detached soil particles in overland flow. As overland flow concentrates downslope it will gain sufficient energy to initiate soil erosion, forming small but well-defined channels or rills. Most of the upland sediment is transported downslope by flow in the rills. An advanced stage of rill erosion is gulley erosion, which produces large channels that cannot be smoothed over by normal tillage operations. Flow in surface streams can produce stream-bank erosion which contributes sediment directly to the stream. The processes of sedimentation and erosion can take place simultaneously so that soil can be settling from the same rill of water that is detaching other particles.

The HSPF model is comprehensive in that it attempts to predict both event-based movement of numerous potential pollutants and between event conditions on land, in soil, and in streams. Many of its sediment parameters closely parallel those of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE is not an event based model; it was developed

for estimation of average, annual soil erosion and effects of agricultural practices. A wealth of empirical data has gone into quantification of its parameters. Therefore, some of the HSPF sediment parameters draw heavily on the USLE factors for quantification.

KRER - Coefficient of soil detachment

KRER is a parameter indicating the susceptibility (i.e., detachability) of soil to erosion by rainfall. Since a separate practice parameter (SMPF) is included in the HSPF, KRER does not account for the influence of conservation practices as it does in the ARM model. Thus, KRER is best estimated by the erodibility, K, values for the USLE. The K value is the soil loss rate per rainfall erosion index unit for a specified soil as measured on a unit plot, which is defined as 72.6 ft length of uniform 9 percent slope continuously in clean-tilled fallow. (The rainfall erosion index for a given locality is a function of total storm energy and maximum 30-minute intensity.)

KRER will not change greatly from year to year as a result of practice application because the factors that influence it are inherent in the natural character of the soil. Although the K parameter of USLE is empirically derived, it has been found to relate (in terms of long term soil erosion) to soil particle size distribution, percent organic matter, soil structure and permeability. Of these only percent organic matter and permeability will change significantly as a result of practice application. K is given as (Wischmeier and Smith, 1978):

```
100K = (2.1*M**1.14)*(10**-4)*(12 - a) +
       3.25*(b - 2) + 2.5*(c - 3)                    (4.17)
```

where:

M = the particle size parameter (% silt*(100-% clay))
a = percent of organic matter
b = the soil-structure code used in soil classification
c = the profile-permeability class (values of 1 (rapid) to 6 (very slow))

The K value for Tama silty clay loam is 0.28; other properties of Tama silty clay loam are given in Table 4.6.

Equation 4.17 can be used to calculate the change in K due to an increase in organic matter. Using the values in Table 4.6, equation 4.17 indicates a decrease in K of 0.032 for each 1% increase in organic matter. Therefore, K could decrease from 0.28 to 0.165 due to an increase in organic matter from 2.4% to 6.0%. If we assume that the 2.4% organic matter content reflects the results of years of continuous corn and 6.0% organic matter was in the virgin soil, then we can estimate the relative

TABLE 4.6 PROPERTIES OF TAMA SILTY CLAY LOAM

K = 0.28
Clay = 28%
Silt = 65%
Sand = 7%
O.M. = 2.4% (Assumes OM = 20 x organic nitrogen)
Original O.M. content of virgin soil = 6.0%
(Thompson, 1957, pg. 363)
Permeability = moderate (County Soil Survey)

TABLE 4.7 LONG-TERM ROTATION EFFECTS ON KRER (from Thompson, 1957)

	Percent of Virgin level of O.M.	O.M.(%)	KRER
Continuous corn	40%	2.4	.28
Corn, Corn Oats, Clover	60%	3.6	.24
Corn, Oats, Clover	67%	4.0	.23
Corn, Oats, Hay, Hay	80%	4.8	.20
Corn, Oats, Hay, Hay, Hay	95%	5.7	.17
Virgin	100%	6.0	.16

TABLE 4.8 SUMMARY OF CHANGE IN KRER OVER A LONG PERIOD DUE TO CONTINUOUS APPLICATION OF PRACTICES.

	Maximum Percent Change in KRER		
Practice	O.M.	PER	Total Change
Contour Strip Cropping	-14	-9	-23
Sod-based Rotation (3 corn - 3 hay)	-14	-9	-23
Permanent Meadow	-43	-9	-52
Grassed Waterways	-43	-9	-52
Filter Strips	-43	-9	-52

effects of rotation practices on organic matter content within this range. Although the crop rotations are not currently easily handled by HSPF (see Section 4.5) the change in KRER could be estimated due to this practice as shown in Table 4.7.

Any practice that adds organic matter or that returns residue that might otherwise be removed would also decrease the value of KRER by the same relationship used above. Examples of such practices might be addition of manure or switching from silage corn to grain corn. Since an acre furrow slice of soil contains about 48,000 pounds of organic matter (2.4% of 2 million pounds), changes in KRER resulting from changes in organic matter would occur very slowly (e.g., many years). A winter cover crop if plowed under would slightly increase organic matter but probably not appreciably.

Equation 4.17 can also be used to evaluate the change in K due to permeability changes. If we assume the permeability class could be changed from moderate (class 3) to rapid (class 1), equation 4.17 would produce a 0.05 decrease in K from 0.28 to 0.23 due to the permeability change. It should be noted that the permeability referred to in the relationship with K is the total soil profile permeability. Many practices will greatly influence infiltration but few will affect permeability. Practices that include grass or hay cover that increase the frequency of macropores in the total soil profile can increase soil permeability, whereas tillage operations will affect infiltration but not permeability. No data exist to generalize quantitatively the change in permeability due to change in control practices. Conceivably, a change to 50% or more of the rotation in grass or hay would cause a shift in permeability from 'moderate' to 'moderate to rapid' on Tama silty clay loam. Table 4.8 summarizes the maximum percent changes in KRER due to changes in organic matter and permeability.

One major problem with using K as an estimator of KRER, as suggested in the ARM User's Manual, is that the USLE was developed to determine long-term average annual rainfall erosion whereas KRER is used in modeling erosion processes during short time intervals. K, in effect, is an average value. The susceptibility of soil to detachment is not constant throughout the year. The effect of BMPs on increasing organic matter and therefore changing KRER is not appreciable on an annual basis but permeability (surface infiltration), mechanical detachment, and soil exposure to raindrop impact will vary seasonally and with tillage operations. Dangler and Swaify (1976) have shown that erodibility for the same soil in Hawaii can differ greatly depending on the antecedent moisture conditions.

Tillage mechanically dislodges soil particles and detaches aggregates so that they are readily available to wash off the

surface by the next runoff event. Tillage also increases the surface area of soil exposed to raindrop impact. Unfortunately, these two effects of tillage are not easily quantified. Several researchers have shown that tillage increases the surface roughness and therefore, the soil surface exposed to raindrop impact (Mitchell, 1970; Gayle and Skaggs, 1978). Moore and Larson (1979) have shown that random roughness (defined as the standard error of point elevations within a plot) is almost tripled by plowing. Furthermore, this roughness decreases with rainfall such that a 3 inch per hour rain for one hour on plowed plots reduced the roughness to a value approaching the unplowed condition.

Siemens and Oschwald (1976) studied the effects of several tillage systems on soil loss from simulated rainfall. Unfortunately, they did not have a completely untilled plot for comparison, but they did have a system of chop-plant operations which only disturbed the soil slightly. In their study they moldboard plowed plot A on Nov. 4 and disked it on April 28. They chisel plowed plot B on April 28. The chop-plant plot is referred to as plot C. All plots were planted to corn on April 28. Rainfall was simulated on the plots about 15 days later. No significant rain fell from the time of planting to the test period.

The data from the experiment of Siemens and Oschwald indicates that the soil loss was about 6 times greater on plot A and twice as much on plot B than on plot C. Part of this effect was due to greater residue cover on plots B and C as compared to A. If one assumes the effects of residue on soil loss can be separated out by using the information in Figure 6 of Wischmeier and Smith (1978) then the direct effects of tillage could be inferred from the experiment. From Wischmeier and Smith the soil-loss ratio due to residue on plots A, B and C would have been 1.0, 0.75 and 0.25, respectively. Therefore, the residue effect alone would not completely explain the observed soil loss from the moldboard plowed plot (i.e., a factor of 4 greater vs. a factor of 6 observed). On the other hand, the soil-loss for chisel plowing as compared to chop-plant seems somewhat low based on the residue cover only (i.e., a factor of 3 greater expected and only about a factor of 2 greater observed).

A further complication of the above mentioned study is that even after 10 inches of rainfall (2.5 inches per hour for 4 hours) the rate of soil loss remained constant for all plots. This information suggests that the decrease in soil detachability (KRER) that is expected following tillage is either not greatly affected by rainfall on the tilled soil or occurs at a level greater than 10 inches. Incidentally, runoff was also constant after 10 inches of simulated rain on all plots.

KRER might be assumed to decrease following tillage because of increased infiltration due to that practice. The analysis for INFILT suggests that parameter increases by 50 percent immediately following tillage regardless of supporting practices in use. This effect alone, as discussed earlier, would cause a maximum decrease in KRER of about 9 percent.

Therefore, while it seems reasonable and even likely that tillage would influence KRER for at least a short period after the field operation, this relationship is yet undetermined.

SMPF - Supporting management practice factor

SMPF is the parameter that accounts for the influence of supporting management practices on erosion. The values of SMPF can be best estimated as equal to the P-values given in Wischmeier and Smith (1978). The values of P are based on limited data and P is probably the least reliable of the USLE parameters.

Those practices for which SMPF is expected to vary include contouring, graded rows, contour strip-cropping and terracing. The values of P (also SMPF) for contouring are given in Table 4.9. The maximum lengths listed in the table are for guidance to prevent overtopping of the contour ridges. The maximum length values were developed for using P in the USLE to predict annual average erosion. For very large single events, these maximum lengths might be excessive.

The recommended P values for contour strip cropping are given in Table 4.10. Terracing is very often done with contour tillage. The P values given in Table 4.11 include the combined effect of terracing and the other practices noted in the table. These values include entrapment efficiency and are used for control of offsite sediment and for estimating the field's contribution to watershed sediment yield.

The effectiveness of graded rows for erosion control was comparable to terraces in one Iowa study (Moldenhauer et al., 1971). According to Wischmeier and Smith (1978), " P values similar to those for terracing seem appropriate " for graded rows.

COVER - land cover parameter

The parameter COVER(M) is time dependent and quantifies the effects of vegetative canopy and residue on soil particle detachment. Both crop canopy and residue directly reduce raindrop impact, but they also prevent surface sealing and thus cause runoff to be reduced by maintaining a higher infiltration rate (Meyer et al., 1975; Baker and Laflen, 1979a). The crop

TABLE 4.9 P VALUES AND SLOPE-LENGTH LIMITS FOR CONTOURING.

Land Slope Percent	P Value	Maximum Length Feet
1 to 2	0.60	400
3 to 5	.50	300
6 to 8	.50	200
9 to 12	.60	120
13 to 16	.70	80
17 to 20	.80	60
21 to 25	.90	50

TABLE 4.10 P VALUES, MAXIMUM STRIP WIDTHS, AND SLOPE LENGTH LIMITS FOR CONTOUR STRIP CROPPING.

Land Slope Percent	P Values	Strip Width Feet	Maximum Length Feet
1 to 2	0.45	130	800
2 to 5	.38	100	600
6 to 8	.38	100	400
9 to 12	.45	80	240
13 to 16	.52	80	160
17 to 20	.60	60	120
21 to 25	.68	50	100

TABLE 4.11 P VALUES FOR CONTOUR-FARMED TERRACED FIELDS.

Land Slope percent	Computing Sediment Yield: Graded channels sod outlets	Steep backslope underground outlets
1 to 2	0.12	0.05
3 to 8	.10	.05
9 to 12	.12	.05
13 to 16	.14	.05
17 to 20	.16	.06
21 to 25	.18	.06

canopy development is seasonally time dependent while the residue influence decreases radically with tillage and more gradually as the residue decays. The residual effect of sod on reduced soil detachment becomes insignificant about two years after plowed under.

The assumed relationship between COVER and the C factor of the USLE is:

$$COVER = 1 - C \qquad (4.18)$$

Seasonal C-factor values can be calculated as shown by Wischmeier and Smith (1978). Monthly values can be determined by linearly interpolating between the beginning and end of seasonal values. Although the C factor is our best current method of estimating the COVER parameter when land cover data is lacking, it is clear that the C values include considerations other than just protection of the soil surface from raindrop impact.

Determination of C factors for some practices including crop rotations, contour strip cropping and winter cover crops requires the use of a so-called sod factor. This factor is a direct multiplier that has an initial value of about 0.25 immediately after turning the sod, and increases to 1.0 after about two years

The final variable needed for determination of C is crop stage period which is defined by emergence, canopy development, harvest, and tillage. For this study emergence is assumed on May 15 and harvest on November 10. Canopy development is assumed to follow the relationship in Equation 4.3, where CP(t) is the fraction of the ground not covered and L(t) is the fraction of the time period between emergence and full canopy still remaining. Growth curves developed by Hanway (1960) for corn in Iowa show full leaf development after about 56 days.

Wischmeier and Smith (1978) define six crop stages as follows:

Period F (rough fallow)	- Inversion plowing to secondary tillage.
Period SB (seedbed)	- Secondary tillage for seedbed preparation until the crop has developed 10 percent canopy cover.
Period 1 (establishment)	- End of SB until crop has developed a 50 percent canopy cover.
Period 2 (development)	- End of period 1 until canopy cover reaches 75 percent.
Period 3 (maturing crop)	- End of period 2 until crop harvest. This period was evaluated for three levels of final crop canopy.
Period 4 (residue or stubble)	- Harvest to plowing or new seeding.

These crop stage periods are not fixed but rather vary with type of crop, location and tillage practice.

Canopy development is one factor that determines the length of crop stage periods. Based on equation 4.3, canopy development for corn is given below:

Percent Canopy	Days Since Emergence
10	12
50	43
75	52
100	56

Canopy development of other crops would probably not be the same as for corn but the same relationship has been assumed for beans, winter cover crop and hay in the example given below. The following sections demonstrate the development of COVER values for various BMPs using the procedures of Wischmeier and Smith(1978) and the assumptions discussed above.

<u>Conventional Tilled Continuous Corn</u>

Schedule of operations are as follows

Fall Plow	November 15
Plant	May 7
Emergence	May 15
Harvest	November 1

Assuming good productivity with residue left in the field, the following values result:

	COVER
November 15 - May 7	.51
May 8 - May 27	.30
May 28 - June 29	.43
June 30 - July 10	.59
July 11 - November 14	.76

No-tillage and Conservation Tillage

The effect of residue due to no-till and conservation tillage depends on the amount of residue left on the surface. The following values are based on 4500 pounds per acre of residue left in the spring.

	COVER					
	No Tillage			Cons. Tillage		
Percent Residue	90	70	50	70	50	30
May 8 - May 27	.97	.92	.85	.91	.86	.79
May 28 - June 24	.97	.92	.85	.92	.87	.82
June 30 - July 10	.97	.92	.86	.93	.89	.85
July 11 -Nov. 1	.97	.84	.91	.93	.91	.87
Nov. 1 - May 7	.86	.91	.73	.82	.81	.79

Spring Plowing

Spring plowing is assumed to be done April 15, producing the following values

	COVER
Apr. 15 - May 7	.64
May 8 - May 27	.40
May 28 - June 29	.48
June 30 - June 10	.59
July 11 - Nov. 1	.80
Nov. 1 - Apr. 14	.70

Crop Rotation

Although COVER can be determined for crop rotation other aspects of HSPF usage require additional considerations for estimating the effects of this practice. (See Section 4.5)

Sod-based rotation is assumed to be done on a corn-corn-hay sequence. Hay is assumed to yield 2 to 3 tons per acre after direct seeding, planted on April 1 and fall plowed on November 15, producing the following COVER values:

		COVER
Hay -	Nov. 15 - Apr. 1	.51
	Apr. 1 - Apr. 12	.40
	Apr. 12 - May 13	.48
	May 13 - May 22	.67
	May 23 - Nov. 15	.95
Corn -	Nov. 16 - May 8	.85
	May 8 - May 27	.68
	May 28 - June 29	.74
	June 30 - July 10	.79
	July 11 - Nov. 1	.87
	Nov. 1 - Nov. 15	.84
Corn -	Nov. 15 - May 7	.63
	May 8 - May 27	.40
	May 28 - June 29	.52
	June 30 - July 10	.63
	July 11 - Nov. 1	.77
	Nov. 1 - Nov.15	.76

Note that sod will not affect row crop rotation beyond two years. Therefore, in a rotation of C-C-C-H, the third year of corn would have the same soil loss ratios and COVER values as continuous corn.

Crop Rotation of corn and beans with beans assumed to be planted and harvested on May 27 and October 10, respectively, results in:

		COVER
Corn -	Nov. 15 - May 7	.48
	May 8 - May 27	.19
	May 28 - June 29	.35
	June 30 - July 10	.49
	July 11 - Nov. 1	.75
	Nov. 1 - Nov. 15	.75
Beans -	Nov. 15 - May 27	.47
	May 28 - June 17	.27
	June 18 - July 19	.39
	July 20 - July 31	.59
	Aug. 1 - Oct. 10	.79
	Oct. 11 - Nov. 16	.82

Improved Soil Fertility

Improved Soil Fertility is estimated to affect cover by increasing the rate of canopy development by approximately the same percentage as expected crop yield increases. For example, corn is assumed to reach full canopy development in 56 days under optimum fertility. If soil fertility deficits exist, full canopy development will require more than 56 days. Thus, if 20, 40, and 60% improvements in fertility and yield are desired, canopy development times could be assumed to increase to 67, 78, and 90 days, respectively, under the deficit conditions. These longer development rates would have the following COVER values:

	% Fertility Yield Improvement Required		
COVER	20	40	60
.51	Nov. 15-May 7	Nov. 15 - May 7	Nov. 15-May 7
.30	May 8-June 1	May 8-June 4	May 8-June 7
.43	June 2-July 4	June 5-July 13	June 8-July 22
.59	July 5-July 16	July 14-July 26	July 23-Aug. 7
.76	July 17- Nov. 14	July 27-Nov. 14	Aug. 8- Nov. 14

The above procedures demonstrate the estimation of the COVER parameter based on the USLE C factor. In HSPF the COVER parameter simply represents the fraction of the land surface protected from raindrop impact by crop canopies, crop residues, jute matting, etc. Thus the C factor, defined as the ratio of soil loss under specified conditions to the corresponding loss from continuous fallow areas, obviously includes considerations in addition to protection of the land surface. In practice COVER values for the HSPF and ARM models have been estimated from aerial land surface photographs taken during the growing season to determine the fraction of protected land surface. It appears that the major differences between these methods of estimating COVER relate to periods of fallow or minimal canopy/residue cover. In past studies COVER values of 0 to 15% have been used for fallow or minimal residue periods to allow for field borders, fringe areas, crop stubble, etc., whereas the minimum COVER values from the USLE procedures are in the range of 30 to 40%. Thus the COVER values developed from the C factor procedures should be adjusted downward to reflect only the effects of land surface protection.

AFFIX - Soil compaction factor

AFFIX is a soil compaction factor that reduces the amount of detached soil particles available for transport following tillage. The processes involved in soil compaction and aggregation are undoubtedly extremely complex but the primary variable is antecedent rainfall. Studies by Moore and Larson (1979) and Mitchell (1970) are examples of experiments that

showed a decrease in soil roughness (indicating soil compaction) following rainfall.

Very limited data suggest that AFFIX might decrease from an initial high value to one that approaches zero after about three inches of rain has fallen on the tilled soil. Since AFFIX is related to raindrop impact it is indirectly related to the crop canopy and residue cover also.

Unfortunately, in HSPF AFFIX is defined as a rate constant that indicates decreases in detached soil with time, not mass rainfall. Given the nature of AFFIX and its implementation in HSPF, an estimate of it as a constant is given as:

$$AFFIX = (1.0 - COVER)/10 \qquad (4.19)$$

This expression results in the range of values, .1 to .001, used in past studies. However, this equation should be used with caution since it has not been validated with field data. A conservative approach would be to keep AFFIX constant for different BMPs because of the uncertainties in estimating its values.

KSER, KGER - Soil transport and detachment parameters

KSER and KGER are parameters used to indicate the transport and detachment (scour) of fines, respectively. Both parameters depend on slope, slope length, roughness and sediment particle size distribution. Conceptually, these parameters are different but in terms of the effect of BMPs on them they are similar. Foster and Meyer (1972) and Neibling and Foster (1979) concluded that the Yalin equation (Yalin, 1963) could be used to compute sediment transport capacities for overland flow. Hydrocomp International (1975) using this approach tried with very limited success to relate these parameters to Manning's 'n' and various other variables by using regression analyses. Power function representations of a sediment rating curves can be used to estimate initial values of these parameters, if the observed data can be reasonably assumed to represent primarily the effects of erosion processes. Also only data points in the region where the sediment is being transported at or near capacity, such as storms following tillage events, should be used in the analyses.

The concept of tractive force suggests that KSER and KGER should increase directly proportional to increases in slope and slope length (Graf, 1971). However, the processes involved in quantifying these two parameters include more than just tractive force. Values of the LS parameter of the USLE are based on empirical observations that are closely related to those that affect the HSPF parameters. The effects of slope and slope

length on KSER and KGER can be estimated as proportional to the LS-factor (Schwab et al., 1966) defined as follows:

$$\text{LS-factor} = ((L/73)^{**}0.5)*(0.065 + 4.6*S + 64.4*S^{**}2) \qquad (4.20)$$

where:
L = slope length in ft
S = slope in ft/ft.

Practices that might influence slope or slope length include terraces and graded rows.

Both KSER and KGER are related to surface roughness but in a way that is only generally defined. While attempts have been made to define values of Manning's 'n' for overland flow (Ree et al., 1977) a better measurement of the effect of surface roughness on HSPF soil scour and transport parameters is the vegetative density parameter "a", discussed previously in Section 4.2. This parameter is more appropriately defined for agricultural fields and has been quantified by Holtan for many agricultural land uses. High values of 'a' indicate greater surface friction which will reduce runoff velocity and also volume. The volume of runoff decreases because of greater infiltration under densely vegetated areas.

As an approximation, KSER and KGER can be assumed to be related to the inverse of the vegetative density parameter 'a'. Table 4.12 lists values of 'a' for several selected practices. Changes in the value of KSER and KGER as a result of practice application can be determined by multiplying the initial calibrated values by LS/a, where LS is given by equation 4.20, and a is taken from Table 4.12.

Since the above procedures are new and have not been tested with observed data, they should be used with caution. Both KSER and KGER should be refined by calibration with observed data; KGER should be set to zero or a small value if gullying and/or scour is not evident on the watershed. A conservative approach to analyzing BMPs would be to use the calibrated values of these parameters for all practices. Actual sediment loss will change with changes to the other sediment and runoff parameters.

DETS - Detached sediment storage

The state variable DETS represents the pool of detached soil particles on the field surface ready to be transported. It has units of tons/acre and is greatest immediately after tillage. There is no direct data to quantify DETS but data such as surface roughness resulting from tillage might be used to show trends in DETS as a result of various practices. In a study by

TABLE 4.12. VALUES OF 'a' FOR DETERMINATION OF OVERLAND FLOW SEDIMENT COEFFICIENTS

Practice	a
Base	0.1
No Till	*
Conservation Till	*
Graded Rows	0.1
Contour Strip Cropping	0.2 (0.3)**
Sp. Plow	0.1
Winter Cover Crop	0.15
Permanent Meadow	1.0
Mech. Cult.	0.1
Crop Rotation	0.1
Terraces	0.1
Diversions	0.1
Grassed Waterways	1.0
Filter Strips	1.0
Tile Drainage	0.1
Retention Basins	0.1

* a = 0.1 + 0.4 (Fraction of surface covered by residue)
No Till 90% Residue a = 0.46
Conservation Till
Chisel Plow 65% Residue a = 0.36
Light Disc 70% " a = 0.38
Heavy Disc 30% " a = 0.22

** If sod-based rotation effect included.

Moore and Larson (1979) cited earlier, plowed fields were 2.5 times as rough as unplowed fields immediately after tillage.

Obviously DETS is a function of many factors, the most important of which are the type, severity, and number of tillage operations and soil characteristics indicating its susceptibility to detachment (e.g. size distribution, organic matter). Past modeling studies have shown an overall range of values of 0.5 to 5.0 tons/acre, with most values in the range of 1.0 to 3.0 tons/acre. Representative values for different tillage operations calibrated in a recent study on a Mississippi Delta watershed (Sharkey silty clay soil) were as follows (Hydrocomp, Inc., 1979):

Plow, light/single disking	1.0 Tons/acre
Cultivation for weeds	2.0 Tons/acre
Multiple disking for seedbed preparation	3.0 Tons/acre

In HSPF, the Special Actions option is used to reset the value of DETS for each tillage operation. Calibration is the most appropriate way to evaluate the needed adjustment in DETS for different types of operations. BMPs that effect the number and frequency of tillage operations (e.g. no tillage, conservation tillage, mechanical cultivation) can be represented by increasing or decreasing the number and extent of tillage operations by the associated changes to the DETS variable.

4.4 HSPF chemical parameters

In considering BMPs to control the transport of agricultural chemicals with drainage from the land, the chemicals can be divided into three classes depending on their mechanism of transport: those lost primarily with sediment, those lost primarily with water, and those lost with both sediment and water. For those chemicals lost primarily with sediment, erosion control practices are potential BMPs of which conservation tillage, terraces, and some use of sod (in rotation, waterways, filter strips, etc.) play major roles. The important factor for these BMPs is how much they decrease erosion since, as a first approximation, chemical losses can be considered to decrease proportionately.

For water transported chemicals, primarily NO3-N, the key to reducing losses is to decrease leaching. Except for poorly drained soils with low percolation, water soluble chemicals usually do not experience large surface runoff losses because of movement into the soil with infiltrating water. Because the amount of water percolating through the soil profile is not easily controlled, the amounts of these soluble chemicals available for transport must be decreased in order to control runoff losses.

For those chemicals adsorbed to some degree by the soil (partition coefficient, K = 1 to 100 ml/g) and transported with both sediment and water, losses with surface runoff usually greatly exceed leaching losses, and usually exceed surface runoff losses of the more soluble, nonadsorbed chemicals. Adsorption to soil reduces chemical leaching, but for surface-applied chemicals adsorption also reduces the opportunity to move out of the zone of influence of overland flow. One method of reducing losses of these chemicals is to incorporate them into the soil to make them less available for interaction with surface runoff.

The gross impacts on chemical losses expected from use of erosion control, controlling the amount of chemical present, and chemical incorporation are either documented or logical. However, there are many subtle effects and interaction of effects for specific management practices about which very limited data or qualitative information exist at the present time. For instance, it is known that erosion control practices may selectively reduce the transport of larger material which will be less chemically active. Empirical equations can be developed to relate sediment nutrient concentrations (or enrichment ratios) to sediment discharges, but these are very crude and do not apply for some soils or management practices. In addition, the use of conservation tillage, while decreasing erosion, reduces the options to incorporate applied chemicals as well as changing the temperature, moisture, and aeration conditions which in turn can affect the potential for chemical losses.

Therefore, the impact of certain BMPs on a few model parameters may be well established, but for a large number of BMP-model parameter combinations, at best, only qualitative information is available. In the absence of quantitative information, it is usually adviseable to take a conservative approach and assume a parameter is constant and not affected. The following portions of this section discuss the various chemical parameters and their adjustment to represent BMPs.

SPS, UPS - Surface and upper zone storage of chemicals (except nutrients)

SPS and UPS are state variables representing chemical storage in the surface and upper zones, except for nutrients and tracers which have separate state variables. Each variable is a 3-dimensional array to allow differential accounting and application of the solution, adsorbed, and crystalline forms of the chemical. Chemical applications, incorporation, and tillage impacts on the amount and distribution of applied chemicals are accommodated in HSPF through the use of the Special Actions

option; SPS and UPS can be incremented or reset to any value at any time during the simulation. Thus, the amount, form, and method of application can be represented through the use of this option. For example, SPS would be incremented for a surface application, and both SPS and UPS would be incremented for the amount and distribution of an incorporated application. The effects of tillage would be represented by resetting the variables to maintain the same total amount of chemical but changing its distribution in the profile.

No-tillage and conservation tillage will result in all herbicides being surface-applied with essentially none incorporated (unless reduced tillage is performed after application), relative to conventional tillage where about 50% is soil-incorporated on corn and soybeans (Jennings and Stockdale, 1978). In addition, for these BMPs, knockdown herbicides may be used to kill weed growth already present at planting. If no knockdown herbicide is used, a post-emergence herbicide may be used to allow the crop to catch up to the weeds. As a rough estimate, in the midwest 1/3 of the no-till and conservation tillage row crop acreage would generally receive knockdown herbicide treatment, 1/3 post-emergence treatment, and 1/3 no extra herbicide. This would be in addition to the pre-emergence herbicides normally applied; however, application rates of the pre-emergence herbicides should be the same for all tillage systems (Erbach and Lovely, 1975). Also, insecticide treatments will likely be identical for all tillage systems.

In a sod-based rotation, of course no chemicals will be applied during the years in grass, but first year corn following grass may require an insecticide treatment for wireworm control; about 43% of this acreage in Iowa was similarly treated in 1977.

For crop rotations with corn following soybeans, no rootworm insecticide should need to be used; however, for corn following corn about 91% of this acreage in Iowa has been shown to be treated with insecticides (Jennings and Stockdale, 1978).

With respect to eliminating other excessive applications, the 1977 Iowa survey (Jennings and Stockdale, 1978) showed that 25% of the corn following soybeans acreage was needlessly treated for rootworm (unless there was a severe volunteer corn problem). Conversions to permanent meadow and the use of grassed waterways and filter strips will reduce the areas treated with pesticides.

Mechanical cultivation will not generally decrease herbicide usage because about 95% of the row crop acres grown in Iowa receive herbicide treatment and about 95% also receive one or more cultivations. In other regions of the country, cultivation may be used to actually replace or decrease herbicide

applications. However, cultivation can change the proportion of a surface-applied pesticide found in the surface zone. In modeling these effects one usually assumes that cultivation results in a uniform vertical distribution of the pesticide down to the depth of incorporation, unless available data indicates some other distribution, such as higher concentrations in the surface zone. In fact, incorporation of applied pesticides where feasible is an effective BMP for reducing chemical runoff losses. Baker and Laflen (1979b) have shown a reduction by a factor of about 3 in runoff losses. If we assume this reduction is due to a comparable reduction in soil surface concentrations, this would indicate that incorporation would allow 1/3 of the surface application to remain in the surface zone. Bode et al.(1979) have made measurements of herbicide incorporation using various tillage tools and operating conditions. Their results indicate that the resulting vertical pesticide distribution depends on speed, depth of operation, disk spacing, disk diameter, etc. and that relatively uniform distributions can result using proper equipment, speed, and depth of incorporation. Table 4.13 summarizes the effects of various application and incorporation procedures on the resulting pesticide distribution in the soil profile.

Optimizing the timing of pesticide applications relates primarily to evaluating the probability of rainfall-runoff events within a short time (few days to a few weeks) following application. Our current predictive methods for weather and rainfall forecast are not sufficiently accurate for this purpose. In most cases farmers will time applications to optimize its effectiveness due to cost considerations, and weather forecasts will often be consulted to minimize potential losses.

Biological control is generally part of integrated pest management (IPM) programs that involve the use of multiple pest control tactics, including pesticides applied generally at rates lower than conventionally used (EPA, 1980). IPM systems combining biological and cultural control practices (e.g. crop rotations, residue removal, timing of planting and harvesting) and reduced pesticide applications can be analyzed if the assumptions of the system are clearly defined. For example, it is estimated that scouting techniques to assess the timing and extent of infestations and required pesticide applications for rootworm control in a corn-corn rotation can reduce the treated acreage by 50% (Miranowski, 1980). Such assumptions can be used to develop parameter estimates to evaluate biological control and IPM systems.

For controlled release pesticides, in which the active compound is encapsulated in a polymer, Sinclair (1973) has presented data for a specific polymer that shows the effect of controlled

TABLE 4.13 EFFECT OF APPLICATION METHOD ON FERTILIZER AND PESTICIDE DISTRIBUTION IN THE SOIL PROFILE

Method	Common Procedure	Distribution
Broadcast	Spread as dry granules or a spray over the whole surface	Remains on soil surface
Plow-down	Plowing after broadcast application	Turn over of soil results in layer at plow depth (15 cm)
Disked-in	Disking after broadcast application	Assume uniform distribution from surface to tillage depth (10 cm)
Chisel-plowed	Chisel plowing after broadcast application	Assume linear decrease in distribution with depth to zero amount at tillage depth (15 cm)
Surface-banded	Spread as dry granules or a spray over a fraction of the row	Remains on soil surface in a horizontal band
Banded-incorporated	Spread as dry granules or a spray over a fraction of the row and incorporated in planting operation	Assume uniform distribution to depth of incorporation (5 cm)
Side-band*	Applied as dry granules or a liquid 5 cm from and slightly below seed	Assume lines at depth of 5 cm
Knifed-in*	Applied as liquid in rows, often anhydrous ammonia	Assume lines at depth of 15 cm
Point-injected	(in development stage for liquids)	Assume points at depth of 7.5 cm

*These methods are not used for pesticides.

release on the amount present in the soil with time, assuming that the pesticide remaining in the capsule is unavailable to be lost by other means. His data indicate that the release of active ingredient could be characterized as a first-order mechanism. Presumably, pesticide manufacturers would have such data from which the release function and rate could be determined for specific controlled release pesticides. In HSPF, this alternative BMP could be modeled by assuming daily sequential applications of the pesticide in amounts predicted by the release rate. For example, if the release is proportional to the amount present at a rate of 0.5 per day, a 2 lb/ac application would be equivalent to daily applications of 1.0, 0.5, 0.25, 0.125, 0.068, 0.034, etc. However, if the release rate is a function of environmental variables (temperature, moisture, radiation, etc.) additional assumptions would be needed to develop the equivalent daily application sequence.

SN/SP , UN/UP - Surface and upper zone nutrient storages

SN, SP, UN, and UP are the nutrient state variables for the surface and upper zones analogous to SPS and UPS. Nutrient (fertilizer) applications are accommodated in HSPF similar to pesticides. Application amounts are specified in terms of nitrogen in the nitrate (plus nitrite), solution ammonium, adsorbed ammonia, or organic nitrogen forms, and phosphorus in the solution phosphate, adsorbed phosphate, and organic phosphorus forms.

The no-tillage BMP results in all the fertilizer being surface applied with none incorporated, except for the case of anhydrous ammonia being knifed-in or side banded (Table 4.13). It is estimated that 50 to 60% of the nitrogen applied in Iowa is applied as anhydrous ammonia (Voss, 1980). If starter fertilizer was banded with the seed at planting, this could result in some incorporation but at present this practice is not wide-spread enough in many areas of the midwest to be of any consequence.

With conservation tillage the fertilizer applied before any tillage operation can be assumed to be incorporated to the same degree as the residue incorporation resulting from tillage operations. For example, if it is assumed that disking reduces surface residue by 60%, then the nutrient concentration in the surface zone would be 40% of that for fertilizer surface-applied without incorporation, with the remainder in the upper zone. The residue reductions for different tillage activities noted in Table 4.2 and the information in Table 4.13 should be used to determine the most appropriate way to represent different application and tillage methods. It should be noted that broadcast fertilizer plowed under will essentially be inverted

with the plow layer and be in the 3" to 6" layer with none in the surface zone. If soil fertility is improved with yearly fertilizer applications, the soil turned up by plowing will have increased nutrient concentrations.

Any fertilizer applied to sod in a sod-based rotation, and to grass in permanent meadow, grassed waterways, and filter strips will be surface-applied and not incorporated after the establishment of the grass. The effect of eliminating excessive fertilizer applications is obvious; timing of application and controlled release options will not usually affect application rates unless uptake efficiency by the crop is assumed to improve. In this case reduced application amounts would be appropriate. Local extension personnel and soil conservation agencies should be consulted to determine recommended nitrogen and phosphorus application rates for optimum utilization for local crops and conditions. For example, current recommendations for nitrogen usage for corn in Tama County, Iowa and surrounding area is 180 lb/ac for up to 150 bu/ac yield; if yield expectations are greater than 175 bu/ac, the recommendation is 230 lb/ac. The effects of reduced applications on runoff losses can be analyzed by assuming a reasonable reduction of 30% or more in these recommended rates, subject to yield constraints and recommendations of local experts.

KDSAM/KADAM, K1 - NH4 adsorption/desorption parameters

K1 is the Freundlich partition coefficient, and KADAM and KDSAM are the first-order adsorption and desorption rate constants, respectively, for NH4. In HSPF, either an equilibrium or kinetic first-order approach can be chosen by the user. For NH4, the equilibrium approach using a K1 value is preferred because more relevant information is available in the literature for partition factors. However a detailed evaluation of the two alternate methods has not been performed.

The adsorption of NH4 to soil should be mainly dependent on the cation exchange capacity of the soil and the mix of cations present in the soil solution. The BMP of increasing soil fertility could displace the equilibrium to more NH4 in the soil solution but definitive evidence is not available. We recommend not changing or adjusting the adsorption parameters for different BMPs unless supported by other information and/or data.

KNI, KDNI, KIMAM, KIMNI, KAM - nitrogen transformation rate constants

These parameters are the first-order rate constants for the nitrogen (N) transformations of nitrification (KNI), denitrification (KDNI), organic N ammonification (KAM), and immobilization (KIMAM, KIMNI). Definitive evidence for the direction and magnitude of the effect of conservation and no-tillage on these rate constants is not available. As an example, data of Bennett et al.(1975) showed considerably more NO3-N in the top 4 feet of soil after corn harvest (189 lb/ac of N applied in the spring) under sod-planted than under plowed plots with most of the difference in the upper 2 feet. This difference disappeared by the following spring. Banvel (1975), in a study comparing corn yields under different rates of N application (0 to 161 lb/ac) with no-tillage and conventional culture, found no difference in the amount and distribution of residual mineral N in the root zone at two sites, with residual mineral N higher for conventional culture at a third site. In yet another study, (Randall, 1980) on continuous corn with 185 lb/ac of N applied each year, after 8 and 9 years from 3 to 4 times as much NO3-N was found in the 0-5' profile for conventional tillage as for no tillage. He concludes this difference indicates loss and poor efficiency of fertilizer N occurred with no-tillage.

Doran (1980) found that corn residue on the soil surface (between rows of corn in the till-plant system) resulted in higher NO3-N content, as well as microbial populations and soil moisture, relative to areas bare of residue (within the row).

For nitrification of anhydrous NH3, Cochran et al.(1975) found that straw placement (or no straw added) had no significant effect on amounts of NH4-N and NO3-N recovered with time. They state:

> "Apparently any competitive effect by microorganisms for NH4-N in straw decomposition was eliminated by the high NH4-N concentrations in the NH3 retention zone, and the partial sterilization of the retention zone by the NH3 did not affect nitrifying activity in the presence of straw differently than in residue-free soil."

For denitrification, which is thought to only occur significantly at lower soil depths under anaerobic conditions, what happens in the plow layer with respect to location of residue would be expected to have minor impact.

The effect of soil additives on the amount of applied NH3 nitrified has been studied by various researchers. Guthrie and

Bomke (1980) present some data on inhibition of nitrification by N-Serve and ATC for soils of different texture. Jarrell and Boersma (1980) present a theoretical treatment of the release of urea from sulfur-coated granules. Meikle (1978a, 1978b) has modeled the effect of N-Serve (nitrapyrin) on nitrification inhibition as impacted by temperature, pH, and organic matter. His results (Meible 1978a) show that the approximate time gained in reaching 50% NH4-N remaining in the soil when N-Serve is applied is about 30 days, i.e. the half-life is increased by about one month. As a first approximation, the KNI parameter can be adjusted so that the half-life is increased by 30 days (e.g. if KNI is assumed to be 0.24/day without N-Serve, then with N-Serve KNI would be equal to .693/((.693/.24) + 30) or 0.0211).

For a more detailed treatment, Meikle (1978a) notes that nitrification is completely stopped when the N-Serve concentration is equal to or greater than 1.05 ppm, and it has no effect when the concentration is less than or equal to 0.05 ppm. Between these extremes, the KNI parameter should by multiplied by the follow activity ratio (Meikle, 1978a):

$$AR = 0.886 - 1.326*(NS) + 0.471*(NS)**2 \qquad (4.22)$$

where AR = activity ratio or correction factor for KNI
NS = N-SERVE concentration, ppm

Since N-Serve disappearance is assumed to be a first-order mechanism affected by temperature, application rate, and organic matter, the original references should be consulted for a detailed treatment of the effects of N-Serve. The above methods can be used to approximate its effect on the KNI parameter.

KADP/KDSP, K1, KIMP, KMP - phosphorus adsorption parameters and transformation rate constants

These parameters are the adsorption/desorption parameters for the equilibrium (K1) and first-order (KADP, KDSP) options, and the organic phosphorus (P) mineralization (KMP) and PO4 immobilization rate constants. There are many forms and tests for P in the soil environment. P in soil can be quantified as total P, resin extractable P, NaHCO3 extractable P, Bray No. 1 available P, and that defined by other chemical or biological soil tests. Because only 5 to 40% of total P is labile or available, total P is not often used in determining soil concentrations for adsorption-desorption and other P availability or reaction rate constants. Because data usually exists from soil fertility tests for plant available P (either Bray No. 1 or NaHCO3 extractable P), these tests will usually be used in determining P adsorbed to soil.

It has been shown (Singh and Jones, 1976) that corn and bean stalk residue incubated with a high P-fixing capacity soil affects the "equilibrium" ratio between adsorbed and solution phases of PO4-P. In the case of corn residue, after 150 days incubation, the P adsorbed by soil in contact with a 0.1 ppm P solution (determined from an adsorption isotherm) was about 180 lb/ac; for check soil, no residue added, the P adsorbed by soil was about 100 lb/ac. In the case of the bean residue the opposite was true; check soil in contact with a 0.1 ppm P solution had adsorbed 100 lb/ac of P; the residue treated soil had adsorbed 90 lb/ac. These trends were also true for desorption isotherms.

However, soil pH also affects P availability (desorption), and there is an interaction between the use of ammonia-based N fertilizer and different tillage systems that affects soil pH. Triplett and Van Doren (1969) found that the surface soil layer (0 - 2 inches) became more acidic for no-till than for plowed plots (N fertilization rates of 120 and 240 lb/ac per year). Soil pH of about 6.8 is optimum for P availability in most soils; lower pH can reduce available P levels by interaction with Al and Fe, higher pH can reduce available P levels by interaction with Ca.

With respect to PO4 immobilization and organic P mineralization, like nitrogen there is little definitive evidence for altering rate constants due to conservation and no tillage practices. As Stanford et al. (1973) stated:

> "...frequently a reduction in N or P availability due to added straw is observed in incubation studies. On the other hand, in the field, with adequate fertilization, little or no reductions or actual increases in nutrient availability are observed."

Therefore until further definitive evidence is available on the effects of practices and soil conditions on P adsorption/desorption and transformations, these parameters should not be changed for alternate BMPs.

KADPS/KDSPS, K1, N1 - pesticide/chemical adsorption parameters

As for ammonia and phosphate adsorption, HSPF allows both a kinetic first-order and equilibrium approaches to pesticide (chemical) adsorption/desorption. KADPS and KDSPS are the first-order adsorption and desorption rates, respectively, and K1 and N1 are the Freundlich isotherm parameters. Previous experience with these parameters involves primarily the Freundlich equilibrium approach since it was the only method

used in the ARM model. Unless additional research and data support a first-order kinetic approach, the equilibrium approach is recommended with the parameters developed from isotherms of the relevant chemical-soil combination. With N1 = 1.0, K1 becomes the partition coefficient for a linear isotherm which is appropriate for many pesticides in the range of concentrations expected in agricultural soils. The ARM User's Manual, and recent work by Pionke and DeAngelis (1980) provide guidance in estimating partition coefficients.

Although there is minimal evidence from which adjustments to the adsorption parameters for different BMPs can be quantified, it is clear that certain practices can influence the adsorption process. The lower pH of surface soils resulting from the application of NH3 based nitrogen fertilizer affects the adsorption of basic (e.g. the s-triazines) and acidic pesticides to soil. In the case of basic pesticides, hydrogen ions in acidic soils protonate the pesticides to form positively charged ions which are readily adsorbed at the negative sites of soil particles. In neutral or alkaline soils the basic compounds remain primarily in a nonionized form and are held much more weakly by soil particles. In the case of acidic pesticides (e.g. chloramben, dicamba, 2, 4-D, picloram, and dinoseb) in neutral and alkaline soils, a portion of the pesticide ionizes to form a hydrogen ion and an anion, which is not readily adsorbed. In acid soils this ionization is suppressed and more of the pesticide remains in the neutral form. In the neutral form these pesticides are more subject to adsorption, particularily by the organic portion of the soil (Grover, 1977).

For atrazine adsorption to a clay loam soil (6.3% organic matter), an increase in soil pH from 3.9 to 8.0 was found to decrease the distribution coefficient (Kd) from 12.6 to 6.3 at 20 degrees C; temperatures in the range of 0.5 to 40 degrees C did not affect Kd significantly (McGlamery and Slife, 1966).

BMPs that include crop residues and/or sod can increase partition coefficients if they lead to increases in the organic matter or organic carbon content of the surface soils. Studies and data from Karichhoff et al. (1979) and Rao and Davidson (1980) indicate the organic carbon (and associated organic matter) of the soil is the primary adsorption mechanism for many soils and pesticides. If the impact of selected BMPs on the soil organic matter can be estimated, changes in the partition coefficients can be approximated assuming the organic matter is the major adsorption medium.

Except for BMPs which include pH and organic matter adjustment of the soil, we recommend not changing the adsorption parameters for the candidate BMPs unless specific evidence or data to the contrary is available.

SDGCON, UDGCON - surface and upper zone degradation rates

These parameters are the first-order decay rates for pesticides (chemicals) in the surface (SDGCON) and upper (UDGCON) soil zones. HSPF also includes similar decay rate parameters for the lower and groundwater zones but the processes in these zones are not usually affected by agricultural practices. Lacking site-specific data on soil persistence, these parameters are usually evaluated from literature data with similar pesticides, watershed, and soils data. Nash (1980) and Rao and Davidson (1980) have recently presented a wealth of information on the dissipation of pesticides from soils, and the ARM User Manual provides guidance on estimating these parameters from estimated half-lives and persistence for selected pesticides.

Obviously, agricultural practices that affect the nature and characteristics of the soil surface and upper root zone will impact pesticide persistence. Unfortunately, the available data is insufficient to clearly quantify these impacts. Also, the lumped pesticide persistence approach in HSPF is the summation of numerous attenuation mechanisms (e.g. photolysis, hydrolysis, volatilization, biodegradation) which will be affected differently by different practices. For example, the increased adsorption of acidic and basic pesticides in acidic soils as noted above should also decrease the rate of degradation of these pesticides since they are less available in the adsorbed state for decomposition by microorganisms (Mayer er al., 1972). However, in some cases, adsorption to soil has been found to catalyze chemical hydrolysis of atrazine (Armstrong and Chesters, 1968). Simazine, another s-triazine herbicide, was found to be more persistent in a no-till, higher pH soil, than a conventionally tilled, lower pH soil (Slack et al., 1978); unfortunately, bioassay was used to quantify simazine persistence, and interaction between soil pH and simazine phytotoxicity could have produced substantial error.

As with other chemical parameters, we recommend not changing the SDGCON and UCGCON decay parameters for different BMPs unless more definitive information becomes available. Since different decay rates are used for the surface and upper zones, BMPs that change the vertical distribution of a pesticide will result in different persistence rates depending on the difference in the decay rates in each zone. Thus, if subsurface decay is slower than surface decay, BMPs that include chemical incorporation will inherently lead to longer soil persistence.

KPLNM, KPLPM - nutrient plant uptake rates

These parameters are the first-order rates for uptake of nitrogen (KPLNM) and phosphorus (KPLPM) by a growing crop. The

rates are input on a monthly basis. The nitrogen uptake is derived from nitrate and/or solution ammonia (with the division specified by the NO3UTF and NH4UTF parameters) and phosphorus uptake is derived from the solution phosphate.

Plant uptake of N and P for all types of tillage can be assumed to be directly related to plant yield, and for most cases yields for conservation tillage, no-tillage and most of the candidate BMPs are not significantly different from those for conventional tillage. However, BMPs that include changes in the type of crop grown on the field, such as winter cover crops and permanent meadow, will require adjustments to the uptake rates to reflect the new or different vegetation. Also, improvement in soil fertility implies an improvement in crop yields; a corresponding increase in nutrient uptake would result.

In HSPF, nutrient uptake rates are estimated initially and then adjusted so that the timing and total uptake correspond to the nutrient content of the expected yields. Local values for both crop yields and nutrient content should be used when available. Stewart et al. (1975) and the ARM User Manual include sample growth/uptake curves and nutrient content of various crops and yields. Voss (1980), Hanway (1971), and Hanway and Thompson (1971) present additional information from which the nutrient uptake amounts and timing can be derived.

ASLT/BSLT, ULTP1/ULTP2 - soil temperature regression parameters

These parameters are the intercept and slope for the regression equations relating surface (ASLT/BSLT) and upper zone (ULTP1/ULTP2) soil temperatures to air temperature. Changes to the intercept will effect uniform changes in soil temperature, while adjustments to the slope impact the sensitivity of soil temperature to air temperature.

Residue on the soil surface for no-tillage and conservation tillage systems will lower the temperature of the surface soils somewhat (.5 to 5 C) depending on, among other things, the amount of residue. Table 4.14 shows data from Doran (1980) for soil temperatures at a 5 cm depth for two residue amounts. A similar effect is apparent for spring plowing, with fall-plowed soils warming quicker in the spring. Because of the continuous cover provided by permanent meadow, grassed waterways, and filter strips, these areas should have cooler soil temperatures than fallow or crop lands (Willis and Amemiya, 1973).

Since the effects of practices on soil temperatures are so dependent on local conditions, local data should be used to the extent possible. The references cited above and work by Cruse

et al. (1980) and Van Doren and Allamaras (1978) can be consulted to provide a more detailed treatment of soil temperature changes. However, the temperature differences are relatively minor in most cases and assuming no changes in soil temperatures will not significantly affect the BMP evaluation.

TABLE 4.14. TEMPERATURE DECREASES (DEGREES C) FOR TWO LEVELS OF CORN RESIDUE ON THE SOIL SURFACE RELATIVE TO NONE*

Residue (t/ha)	May 24	June 1	June 29	July 20	Aug 3	Aug 8	Aug 29
7	2.3	1.1	3.1	0.9	0.9	0.4	1.2
14	4.6	1.9	3.8	1.6	1.5	0.6	2.3

* Data from Doran (1980) for 5 cm depth; data taken at the 15-, 30-, 60-, and 90-cm depths for residue plots averaged 1.0 to 1.5 degrees C cooler throughout the growing season.

SZDPTH, UZDPTH - surface and upper zone soil depths

These parameters are the thicknesses of the surface and upper soil zones used in calculating the soil mass in each zone. The sum of these parameters, i.e. the depth to the bottom of the upper zone, is generally considered to be the average depth of incorporation and tillage. The use of more shallow tillage equipment could reduce the UZDPTH parameter, and more frequent cultivation and/or disking operations could increase the depth of the active surface zone (SZDPTH). However, lacking more definitive data on these parameters, we recommend not changing their values.

If the user varies these parameters for different practices, it would be wise to consider a constant soil mass for each layer by letting the soil depth vary with the inverse of the average bulk density (i.e. the soil depth = soil mass/bulk density). However, soil depths should not be adjusted for temporary changes in bulk density due to tillage (see below).

BDSZ, BDUZ - surface and upper zone soil bulk densities

These parameters are the surface and upper zone soil bulk densities, and as noted above, are used with the soil depth parameters to determine the soil mass in each zone. With more frequent and extensive tillage operations, the bulk density will be less than values for undisturbed areas.

For the Tama soils in central Iowa, bulk densities in the range of 62 to 81 lb/cf (1.0 to 1.3 g/cc) in the surface and upper soil layers are expected. For no-tillage, sod, meadow, grassed waterways, and filter strips a bulk density of 81 lb/cf for the top two layers would be appropriate (Cruse et al., 1980). For conventional tillage a value of 62 lb/cf would be used initially and would increase by the end of the growing season due to compaction and settling. Cultivation and chemical incorporation, if by tillage, would temporarily reduce bulk density to about 62 lb/cf if it was originally greater. For different forms of conservation tillage other than no-till, such as chisel plow and disking, an intermediate value of 72 lb/cf could be used. Similar procedures should be used to adjust these parameters within the range of values expected for local soils.

The Special Actions option is needed to change the BDSZ and BDUZ parameter values whenever tillage operations occur. These parameters should be reset to their original values after an appropriate time following tillage, since settling and compaction by rainfall will cause bulk density to revert to its base value.

4.5 BMPs requiring special consideration for simulation with HSPF

Certain candidate BMPs will require special set-up of HSPF modules and operations in addition to the parameter changes noted above, in order to represent them accurately. These practices, including terraces, contour strip cropping, filter strips, and grassed waterways, modify the surface and/or subsurface flow paths so that they cannot be represented by a single operation of the HSPF PERLND section. Other practices, such as crop rotations and tile drainage systems, need to be discussed in order to determine if the model structure and inherent assumptions are appropriate and reasonable. Each of these practices and their model representation are discussed below.

Terraces and Impoundments

Terrace systems are effective measures to reduce surface runoff, sediment, and sediment-associated pollutants. They are usually classified according to alignment, cross-section, grade, or outlet. Because of the variety of types of terraces possible, the specific implementation of the terrace system to be evaluated must be clearly specified. In addition to changes in the soil and land surface parameters discussed above, the expected flow paths of the proposed terrace system must be analyzed. Since HSPF PERLND assumes a uniform overland flow

path on each pervious land segment (PLS), two or more PLSs may need to be modeled and linked together if the terrace system results in abrupt changes to the overland flow path. For example, in Figure 4.2, the implementation of a terrace system could result in changes in the overland flow path from Figure 4.2a to Figure 4.2b. In Figure 4.2b, the total flow path includes overland flow, terrace flow, and channel flow each of which could be represented by a separate PLS. The outflow of the overland PLS would be input to the terrace flow PLS, whose outflow would then go to the channel PLS to represent the entire flow path. Each PLS would be characterized by a separate parameter set.

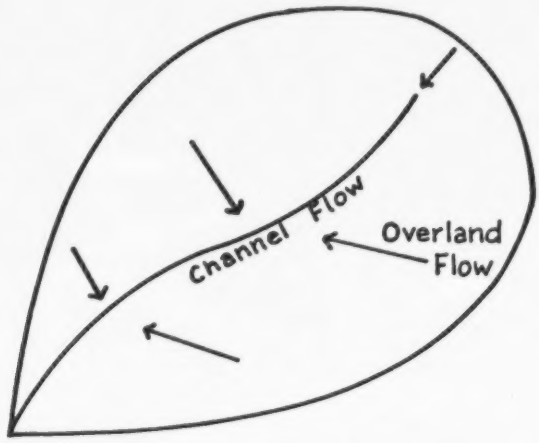
This option of linking different PLSs is a new capability in HSPF not present in the predecessor models. Consequently, it has not been used extensively to date although it is conceptual and mathematically functional.

Figure 4.2c shows a plan and section view of impoundment or tile-outlet terraces, which are common in Iowa and many portions of the midwest. Since the outlet is subsurface, the HSPF PERLND and RCHRES module sections would be used to model this system. RCHRES simulates stream channel and lake/reservoir (well-mixed) systems. To model the impoundment terrace system in Figure 4.2c, HSPF PERLND would model the overland flow and constituents as one PLS providing inflow to the terrace impoundment, and RCHRES would simulate the processes and outflow from the impoundment. Although originally designed for large rivers and reservoirs, RCHRES is sufficiently flexible so that its parameters can be adjusted to represent a terrace impoundment.

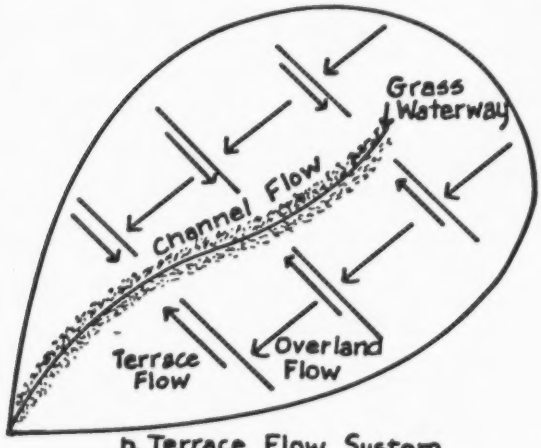
These are two examples of many possible system representations. The key to modeling such systems with HSPF is to clearly define the proposed system and expected flow paths, determine appropriate parameter adjustments, and design combinations of PLSs and/or RCHRES operations to represent the primary component processes that characterize the behavior of the system.

Contour strip cropping/filter strips/grassed waterways

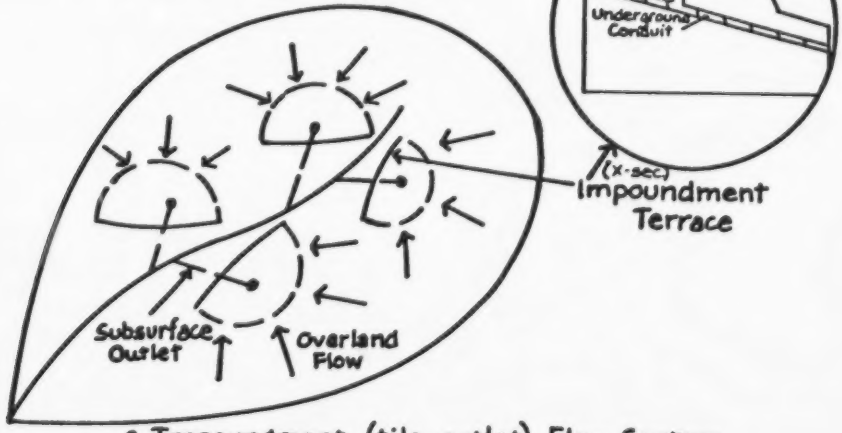
These practices present modeling problems similar to those for terraces discussed above; their implementation results in changes to the initially uniform character of the overland flow path. Contour strip cropping would require the sequential linkage of multiple PLSs with the parameters of each PLS adjusted for contouring. If the cropping system alternates row crops with sod or close-grown crops, the parameters for each PLS could be significantly different since the sod strips would retard runoff and trap much of the eroded sediment.



a. Natural Flow System



b. Terrace Flow System



c. Impoundment (tile-outlet) Flow System

Figure 4.2 Typical Flow Paths for Natural and Terrace Flow Systems

With filter strips or grassed waterways the procedure would be similar except only two PLSs would likely be used; a row crop PLS would be linked to a filter strip or grassed waterway PLS. The only real difference between filter strip and grassed w terway PLSs would be the slope and length of flow (or width) of the filter strip versus the corresponding parameters for flow through the grassed waterway. In Figure 4.2b the channel flow PLS could be replaced with a grassed waterway PLS to analyze the joint effect of terraces and grassed waterways. In each case the expected overland flow path must be clearly defined in order to represent it with appropriate PLS linkages.

Crop rotations

The year-to-year carry-over effects and abrupt changes in land surface characteristics that accompany crop rotation systems, and especially sod-based rotations, are not easily accommodated in HSPF. The carry-over effects on land cover, soil organic matter, fertility, etc. are not built into the model algorithms, but parameter changes can be specified at selected times during the rotation sequence using the Special Actions option. If the carry-over effects can be quantified accurately in terms of parameter changes, careful use of the Special Actions option would allow one to approximate the impacts within the limitations of the model parameters and algorithms.

A more significant problem is to characterize the overall impacts of a 3 or 4 year rotation sequence that has both carry-over effects and abrupt land use/crop changes. The basic philosophy of continuous simulation is to statistically characterize watershed behavior under one set of watershed conditions (land use, management, cropping, etc.) and under the meteorologic conditions represented by the input precipitation and meteorologic data for the simulation period. Abrupt changes in land use during the simulation period will significantly reduce the reliability of the statistical characterization since it will depend on the particular combination of cropping and meteorologic conditions that occur in any one year of the rotation. If a 5-year simulation can reasonably characterize watershed behavior under constant land use/ management practices, then a 4-year crop rotation sequence would require at least a 20-year simulation to obtain a comparable characterization i.e., five occurrences of the 4-year rotation sequence. An alternate approach would be to perform four 5-year runs, lagging the rotation sequence in each run, e.g. a C-C-C-H sequence would also be simulated as C-C-H-C, C-H-C-C, and H-C-C-C. This would allow all particular crop year/ meteorologic data combinations to occur and would gererate 20 years of data from which the crop rotation sequence could be analyzed.

In summary, the crop rotation and sod-based rotation candidate BMPs need to be carefully analyzed, as discussed above or by other procedures, in order to derive a reasonable statistical characterization of watershed behavior.

Tile drainage

Tile drainage is a possible BMP that generally decreases surface runoff and modifies hydrograph recessions. The result is lower flow peaks and flatter hydrographs. It lowers soil moisture levels and hence increases infiltration. In essence, tile drainage introduces a short circuit of flow into the lower and groundwater zones that rapidly moves water out of the catchment following a storm event. However, since tile drains in many areas of the country, such as Iowa, flow year-round, the drain water is derived from both the quick subsurface flow following an event and groundwater, or base flow, that continues for weeks and months. Depending on the type of system, depth of the tile drains (3 to 5 feet in Iowa), and their placement in the watershed, some portion of the tiles will continually drain the groundwater zone while other portions will intercept only the shallow subsurface flow that occurs following storm events.

Due to the formulation of the HSPF PERLND module (and predecessor models), the effects of tile drainage cannot be captured through the interflow parameters (INTFW, IRC). Tile drains at their customary depths of 3 to 5 feet usually deplete soil moisture in the lower zone (LZS) and groundwater zone. However, the interflow parameters in HSPF exert their influence on water detained on or near the surface and upper zone; INTFW specifies the division of this water into surface (and upper zone) detention and interflow, while the IRC parameter controls the outflow (recession) of interflow from storage. In HSPF, interflow is assumed to occur from the upper zone.

In order to more accurately model tile drainage with HSPF, a flow path should be devised to allow accelerated drainage of LZS. Unless the entire structure of the PERLND module is changed, the only apparent way to do this is by modifying the function that allocates infiltrated water between LZS and groundwater storage. The modification should increase the amount of water entering groundwater storage at any lower zone moisture level (LZS/LZSN ratio), and should provide a direct path from LZS to the waterway. Subsequent parameter adjustments would be necessary to increase the rate of groundwater discharge and produce a more rapid recession.

Calibrating the current version of HSPF PERLND on a tile drained watershed will likely produce biased hydrologic parameter values. The infiltration (INFILT) and INTFW parameters would be

higher than expected for natural drainage, and the groundwater parameters would produce more rapid recession and higher baseflow. Thus, the tile drain component of the hydrograph would be simulated as a combination of the interflow and groundwater components. It is unclear how well the quality of tile drainage would be simulated since the modeled values will be derived from groundwater and the top six inches of the soil (surface and upper zones); whereas, in reality, tile drainage water quality is derived from water infiltrating three or more feet into the soil to the depth of the tile drains. Thus, HSPF cannot be readily used to evaluate tile drainage as a BMP, but it can be used in tile-drained watersheds recognizing the possible effect the drains may have on the parameter values.

SECTION 5

RECOMMENDATIONS FOR FUTURE RESEARCH

Our recommendations to improve and expand the capability of using modeling techniques to analyze and evaluate BMPs fall into three categories: practice-oriented research, process and parameter research, and model development research. These categories are not mutually exclusive, but they do follow a natural progression from attaining a better understanding of the processes affected by BMPs, developing better algorithms and parameters values for important processes, and incorporating this knowledge into a modeling framework to develop better analytical tools and models.

5.1 Practice oriented research

Many of the candidate BMPs and especially the nonstructural measures involve the use of crop residues, sod or close-grown crops, and reduction and/or modification of tillage operations. Directed research into the effects of these BMP components on hydrologic, sediment, and chemical processes could significantly improve our analysis of BMPs.

Crop residues are a primary component of the no-tillage and conservation tillage alternatives, and conservation tillage is one of the most popular BMPs gaining acceptance across the country. There is a need to develop better quantitative information on the effects of allowing residues of different crops and in different amounts to remain on the land. These effects should be quantified for the following processes:

a. rainfall interception and soil moisture retention
b. surface roughness and flow retardance
c. land surface cover as affected by decay and decomposition of the residue
d. infiltration
e. sediment transport, scour, and deposition
f. leaching of plant nutrients and effects on soil organic matter
g. washoff and decay of chemicals applied to the residue

Obviously the total effects of no-tillage and conservation tillage are due to the combination of the use of crop residues and reduction/modification of tillage practices (discussed below). Research has been performed and is continuing on many of the processes listed above, but much of the data is contradictory and/or unduly affected by local conditions. Generalized quantitative approaches are needed.

The use and effects of sod or close-grown crops is included in contour strip cropping, sod-based rotations, winter cover crop, permanent meadow, grassed waterways, and filter strips. Thus, understanding how conversion to sod will impact hydrologic, sediment, and chemical processes is important. The information available on sod-type surfaces is better than for many crops, but research into the effects of sod in the following areas is still needed:

a. surface roughness and flow retardance
b. infiltration and soil moisture
c. sediment transport, scour, and deposition
d. particle-size distribution of eroded sediment
e. chemical extraction by growing biomass and flowing water

Perhaps one of the most important research areas is understanding the real effects of tillage practices and different types of tillage and chemical incorporation equipment and operations. A tillage operation causes a complex disruption of a wide range of natural processes; its impact gradually diminishes with time but the rate of disappearance depends on meteorologic and edaphic conditions. Tillage is an inherent part of essentially all agricultural practices. Analyzing BMPs requires understanding the tillage effects on processes, or the impacts of reducing and/or modifying tillage operations from those conventionally used. Our quantitative knowledge in this area is limited, and the effects of different types of operations (e.g. moldboard plowing, chisel plowing, disking, till-planting, cultivation) on the following processes needs to be quantified:

a. residue reduction, surface cover, and interception
b. surface roughness and flow retardance
c. infiltration, soil moisture retention, and surface sealing
d. soil bulk density, aggregate detachment, and aggregate/particle size distribution
e. vertical distribution of applied chemicals
f. soil temperature

5.2 Process and parameter research

This type of research involves the development of a database from which parameter values can be derived for a variety of soils and environmental conditions. The resulting data will provide an opportunity to reassess assumptions, such as first-order nutrient transformations and equilibrium adsorption/desorption. Particular areas for this research include:

a. effects of changes in soil environmental conditions (i.e. temperature, moisture, oxygen) on chemical transformation rates and adsorption parameters as affected by BMPs.

b. effects of soil moisture and other environmental conditions on soil erodibility, detachment, aggregate formation, surface crusting, etc.

c. effects of pesticide formulation (e.g. wettable powders, solution, pellets) and application method on soil persistence rates.

d. kinetics and parameters of the adsorption/desorption process under field and runoff conditions - first-order kinetics versus equilibrium partitioning.

e. extent of plant uptake of nitrogen as ammonia, as opposed to nitrate, to evaluate effects of nitrification inhibitors.

f. occurrence and movement of interflow as related to soils and watershed conditions, and its significance as a transport medium for soluble chemicals.

g. evaluation and quantification of individual decay mechanisms of pesticides in soils i.e. volatilization, photodecomposition, microbial decay.

5.3 Model development research

This study has provided insight into various possible improvements in HSPF in the areas of hydrology, sediment, and chemical simulation.

Hydrology

a. Additional work is needed to better define the UZSN, INFILT, and INTFW parameters in relation to other readily available data. These parameters are still primarily calibration dependent; modifications to the parameter definitions and algorithms should be explored to reduce the need for calibration.

b. Tile drainage is not specifically represented in HSPF. Modifications to the interflow, lower zone, and/or groundwater functions as discussed in Section 4.5 would be needed to better model tile-drained watersheds.

c. The formulation of evapotranspiration from the lower zone in HSPF is highly empirical, and should be modified to be more physically-related and amenable to different types of crops and vegetation.

Sediment

a. The next major improvement in the sediment erosion algorithms in HSPF should be to allow erosion simulation by sediment particle size. This would provide a better physical basis for estimated the sediment transport parameters (i.e. KSER, JSER, KGER, JGER) and would allow a better representation of BMPs that selectively reduce different size particles.

b. The formulation of a pool of detached soil particles (DETS) produced by tillage operations, increased by raindrop impact, and decreased by compaction and aggregation, which are available for transport appears to be a sound concept. However, the effects of different tillage operations on DETS needs further quantification (as noted above), and the reduction in detached particles due to compaction and settling (AFFIX parameter) should be a functional relationship related to soil and meteorologic conditions (e.g. accumulated rainfall or rainfall energy).

c. An effort should be made to incorporate aspects of the supporting management practice factor (SMPF) into other physically-based parameters that would more appropriately represent a cause-effect relationship.

Chemicals

a. Vegetal application and washoff of pesticides is not currently modeled in HSPF. This capability should be added to better represent foliar applications of herbicides and insecticides.

b. The leaching and movement of soluble chemicals in HSPF occurs mainly through the use of calibration-dependent percolation factors and the interflow component. Modeling the movement of soluble chemicals is a difficult problem requiring further study and re-evaluation of the methods used in HSPF. More detailed soil moisture accounting may be needed to track the vertical movement of soluble chemicals. These topics are closely related to the modification needed to represent tile drainage since the tile water quality results from the soluble chemicals in the soil profile.

c. The current regression method of estimating soil temperatures should be replaced with a more physically based method that would allow accommodation of crop canopy, crop residue, and other BMP effects. Such a model would also provide a means of introducing the effects of frozen ground on hydrologic processes.

d. The current 'lumped' approach to pesticide decay in the soil should be re-evaluated to determine if separate decay mechanisms can be modeled. The effects of environmental conditions should also be considered; moisture and temperature dependence of the decay rates could be incorporated into the current version.

SECTION 6

REFERENCES

Anderson, E.A. 1968. Development and testing of snow pack energy balance equations. Water Resour. Res. 4(1):19-37.

Anderson, E.A. and N. H. Crawford. 1964. The synthesis of continuous snowmelt runoff hydrographs on a digital computer. Department of Civil Engineering, Stanford, California. Technical Report 36. 103p.

Armstrong, D.E. and G. Chesters. 1968. Adsorption catalyzed chemical hydrolysis of atrazine. Env.Sci.&Tech. 9:683-689.

Baca, R. G., W. W. Waddel, C. R. Cole, A. Brandstetter, and D. B. Cearlock. 1973. EXPLORE-I: A river basin water quality model. Battelle Pacific Northwest Laboratories,

Baker, J.L. 1980. Agricultural areas as nonpoint sources of pollution. In: Environmental Impact of Nonpoint Source Pollution. Edited by M.R. Overcash and J.M. Davidson. Ann Arbor Science, Ann Arbor, Michigan. pp. 275-310.

Baker, J.L. and J.M. Laflen. 1979a. Effect of corn residue and chemical placement on chemical runoff losses. Paper No. 79-2050, presented at Summer Meeting of ASAE, Winnipeg, Canada.

Baker, J.L. and J.M. Laflen. 1979b. Runoff losses of surface-applied herbicides as affected by wheel tracks and incorporation. J. Environ. Qual. 8:602-607.

Banvel, V.A., S. Dzienia, G. Stanford, and J.O. Legg. 1975. N behavior under no-till vs conventional corn culture. I. First-year results using unlabeled N fertilizer. Agron J. 67:782-786.

Bennett, O.L., G. Stanford, E.L. Mathiss, and P.E. Lundberg. 1975. Nitrogen conservation under corn planted in Quackgrass sod. J. Environ. Qual. 4:107-110.

Beyerlein, D.C. and A.S. Donigian, Jr. 1978. The effects of soil and water conservation practices on runoff and pollutant loss from small agricultural watersheds: A simulation approach. Prepared for Dept. of Agriculture Engineering, Cornell University, Ithaca, New York. 94p.

Bode, L.E., B.J. Butler, and L.M. Wax. 1979. Herbicide incorporation: Which tools work best? Crops and Soils Mag. 31(6):17-20.

Chow, V.T. 1964. Handbook of applied hydrology. McGraw-Hill Book Co. New York, New York.

Cochran, V.L., F.E. Koehler, and R.I. Papendick. 1975. Straw placement: Its effect on nitrification of anhydrous ammonia. Agron. J. 67:537-540.

Crawford, N.H., and A.S. Donigian, Jr. 1973. Pesticide transport and runoff model for agricultural lands. Office of Research and Development, U.S. Environmental Protection Agency, Washington D.C. EPA 660/2-74-013. 211p.

Crawford, N.H. and R.K. Linsley. 1966. Digital simulation in hydrology: Stanford watershed model IV. Department of Civil Engineering, Stanford, California Technical Report 39. 210p.

Cruse, R.M., D.R. Linden, J.K. Radke, W.E. Larson and K. Larntz. 1980. A model to predict tillage effects on soil temperature. Soil Sci. Soc. Am. J. 44:378-383.

Dangler, E.W. and S.A. El-Swaify. 1976. Erosion of selected Hawaii soils by simulated rainfall. Soil Sci. Soc. Am. J. Vol. 40:769-773.

Davidson, J.M., R.S. Mansell, and D.R. Baker. 1973. Herbicide distributions within a soil profile and their dependence upon adsorption-desorption. Soil Crop Sci. Soc. Florida Proc. 26p.

Donigian, A.S., Jr., D.C. Beyerlein, H.H. Davis, Jr., and N.H. Crawford. 1977. Agricultural runoff management (ARM)model version II: refinement and testing. Environmental Research Laboratory, Athens, Georgia EPA 600/3-77-098. 294p.

Donigian, A.S., Jr. and N.H. Crawford. 1976a. Modeling pesticides and nutrients on agricultural lands. Environmental Research Laboratory, Athens, Georgia. EPA 600/2-7-76-043. 317p.

Donigian, A.S., Jr. and N.H. Crawford. 1976b. Modeling nonpoint pollution from the land surface. Environmental Research Laboratory, Athens, Georgia. EPA 600/3-76-083:280

Donigian, A. S., Jr. and H. H. Davis, Jr. 1978. User's manual for agricultural runoff management (ARM) model. Environmental Research Laboratory. EPA-600/3-78-080. Athens, Ga. 162p.

Donigian, A.S. Jr. and N.H. Crawford. 1979. Water quality model for agricultural runoff. Chapter 12 in Modeling of Rivers, by H.W. Shen (ed.). John Wiley & Sons, New York, N.Y. 1979.

Donigian, A.S.,Jr., J.C. Imhoff, and B.R. Bicknell. 1981. Modeling Water Quality and the Effects of Agricultural Best Management Practices in Four Mile Creek, Iowa. U.S. EPA Environmental Research Laboratory, Athens, GA.

Doran, J.W. 1980. Microbial changes associated with residue management with reduced tillage. Soil Sci. Soc. Am. J. 44:518-524.

Erback, D.C. and W.G. Lovely. 1975. Effect of plant residue on herbicide performance in no-tillage corn. Weed Sci. 23:512-515.

Foster, G.R. and L.D. Meyer. 1972. Transport of soil particles by shallow flow. Trans. ASAE. 15:99-102.

Gayle, G.A. and R. W. Skaggs. 1978. Surface storage on bedded cultivated lands. ASAE Trans. 21(1):101-104, 109.

Graf, W.H. 1971. Hydraulics of sediment transport. McGraw-Hill.

Grover, R. 1977. Mobility of dicamba, picloram and 2,4-D soil columns. Weed Sci. 25:159-162.

Guthrie, T.F. and A.A. Bomke. 1980. Nitrification inhibition by N-Serve and ATC in soils of varying texture. Soil Sci. Soc. Am. J. 44:314-320.

Hagin, J. and A. Amberger. 1974. Contribution of fertilizers and manures to the N and P load of waters. A computer simulation. Report submitted to the Deutsche Forschungs Gemeinschaft. 123p.

Haith, D.A. and R.C. Loehr. 1979. Effectiveness of soil and water conservation practices for pollution control. Prepared for the U.S. Environmental Protection Agency. Environmental Research Laboratory. Athens, Georgia EPA-600/3-79-106. 474p.

Harmon, L. and E.R. Duncan. 1978. A technical assessment of nonpoint Pollution. Prepared by Iowa State University, Ames, Iowa. 427p.

Holtan, H.N., G.J. Stiltner, W.H. Henson and N.C. Lopez. 1975. USDAHL-74, Revised model of watershed hydrology. Tech. Bul. 1518. USDA. Washington, D.C. 99p.

Hanway, J. J. 1971. How a corn plant develops. Iowa State University, Cooperative Extension Service. Ames, Iowa. Special Report No. 48. 17p.

Hanway, J. J. and H. E. Thompson. 1971. How a soybean plant develops. Iowa State University, Cooperative Extension Services. Ames, Iowa. 18p.

Hydrocomp, Inc. 1976. Hydrocomp simulation programming: operations manual. Palo Alto, California, 2nd ed.

Hydrocomp, Inc. 1977. Hydrocomp water quality operations manual. Palo Alto, California.

Hydrocomp, Inc. 1978. Sediment loading and agricultural practices in the Kishwaukee and Thorn Creek watersheds. Prepared for the Northeastern Illinois Planning Commission. Hydrocomp, Inc. Palo Alto, California. 45p.

Hydrocomp, Inc. 1979. Estimation of toxaphene concentrations in the mouth of the Yazoo River, MS resulting from basin-wide application of toxaphene to cotton and soybeans. Prepared for U.S. EPA, Athens, Ga. 40 p.

Jarrell, W.M. and L. Boersma. 1980. Release of urea by granules of sulfur-coated urea. Soil Sci. Soc. Am. J. 44:418-422.

Jennings V. and H. Stockdale. 1978. Herbicides and soil insecticides used in Iowa corn and soybean production. 1977. Coop. Ext. Serv. Pub. PM-845, Iowa State Univ., Ames, IA.

Johanson, R. C., J. C. Imhoff and H. H. Davis, Jr. 1980. User's manual for hydrological simulation program-Fortran (HSPF). Environmental Research Laboratory, Athens, Georgia. EPA-600/9-80-015. 678p.

Karichhoff, S.W., D.S. Brown, and T.A. Scott. 1979. Sorption of hydrophobic pollutants on natural sediments. Wat. Res. 13(3):241-248.

Laflen, J.M. 1980. Personal Communication. Iowa State University, Ames, Iowa.

Lull, H. W. 1964. Ecological and silvicultural aspects. Section 6 in V. T. Chow (ed.), Handbook of applied hydrology. McGraw-Hill, New York.

Mayer, J. R., R. J. Hance and C. E. McKane. 1972. The effect of adsorbents on the rate of degradation of herbicides incubated with soil. Soil Biol. Biochem. 4:307-311.

McGlamery, M.C. and F.W. Slife. 1966. The adsorption and desorption of atrazine as affected by pH, temperature, and concentration. Weeds 14:237-239.

Mehran, M. and K.K. Tanji. 1974. Computer modeling of nitrogen transformations in soils. J. Envir. Qual. 3(4):291-395.

Meikle, R. W. 1978a. Prediction of ammonium nitrogen fertilizer disappearance from soils in the presence and absence of N-SERVE nitrogen stabilizers. Soil Science. 127(5): 292-299.

Meikle, R. W. 1978b. Prediction of ammonium nitrogen fertilizer disappearance from soils in the presence and absence of N-SERVE nitrogen stabilizers. Down to Earth. 34(3):6-10.

Meyer, L.D., G.R. Foster, and S. Nikolov. 1975. Effect of flow rate and canopy on rill erosion. ASAE Trans 18(5): 905-911.

Meyer, L.D. and W.H. Wischmeier. 1969. Mathematical simulation of the process of soil erosion by water. Trans. Am. Soc. Agric. Eng. 12(6):754-758, 762.

Miranowski, J. 1980. Iowa State University, Ames, Iowa. Personal communication.

Mitchell, J.K. 1970. Micro-relief surface depression storage. PhD Thesis, Univ. of Ill., Urbana.

Moldenhauer, W.C., W.G. Lovely, N.P. Swanson, and H.D. Carrence. 1971. Effects of row grades and tillage systems on soil and water losses. J. Soil and Water Cons., 26(5):193-195.

Moore, I.D. and C.C. Larson. 1979. Estimating micro-relief storage from point data. ASAE Trans., 22(5):1073-1077.

Musgrave, G. W. and H. N. Holtan. 1964. Infiltration. Section 12 in V.T. Chow (ed.), Handbook of applied hydrology. McGraw-Hill, New York.

Nash, R. G. 1980. Dissipation rate of pesticides from soils. In: CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. W. G. Knisel (ed.) 1980. USDA, Conservation Research Report No. 26. pp.560-594.

Negev, M. 1967. A sediment model on a digital computer. Department of Civil Engineering, Stanford University. Stanford, California. Technical Report 76. 109p.

Neibling W. H., and G. R. Foster. 1979. Sediment transport capacity of overland flow. In: CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. W. G. Knisel (ed.) 1980. USDA, Conservation Research Report No. 26. pp.463-473.

Ogrosky, H. O. and V. Mockus. 1964. Hydrology of agricultural lands. Section 21 in V. T. Chow (ed.) Handbook of applied hydrology. McGraw-Hill, New York.

Olsen, A.R. and S.E. Wise. 1979. Frequency analysis of pesticide concentrations for risk assessment. Battelle Pacific Northwest Laboratories, Richland, Washington. Prepared for U.S. EPA, Athens, Georgia. 116p.

Onstad, C.A. and G.R. Foster. 1975. Erosion modeling on a watershed. Trans. Am. Soc. Agric. Eng. 18(2):288-292.

Onishi, Y., S.M. Brown, A.R. Olsen, M.A. Parkhurst, S.E. Wise, and W.H. Walters. 1979. Methodology for overland and instream migration and risk assessment of pesticides. Battelle Pacific Northwest Laboratories, Richland, Washington. Prepared for U.S. EPA, Athens, Georgia. 204p.

Onishi, Y. and S. E. Wise. 1979. Mathematical model, SERATRA, for sediment-contaminant transport in rivers and its application to pesticide transport in Four Mile and Wolf Creeks in Iowa. Battelle Pacific Northwest Laboratories, Richland, Washington. Prepared for U.S. EPA, Athens, Georgia. 56p.

Pionke, H. B. and R. J. DeAngelis. 1980. Method for distributing pesticide loss in field runoff between the solution and adsorbed phase. In: CREAMS, A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems. W. G. Knisel (ed.) 1980. USDA, Conservation Research Report No. 26. pp.607-643.

Randall, G. W. 1980. Fertilization in conservation tillage. Agrichemical Age. 24:24-28.

Rao, P.S.C., and J.M. Davidson. 1980. Estimation of pesticide retention and transformation parameters required in nonpoint source pollution models. In: Environmental Impact of Nonpoint Source Pollution. Edited by M.R. Overcash and J.M. Davidson. Ann Arbor Science, Ann Arbor, Michigan. pp. 23-67.

Rawls, W.J., C.A. Onstad, and H.H. Richardson. 1980. Residue and tillage effects on SCS runoff curve numbers. In: CREAMS (see ref. for Pionke and DeAngelis). pp. 405-425.

Reddy, K.R., R. Khaleel, M.R. Overcash, and P.W. Westerman. 1979. A Nonpoint Source Model for Land Areas Receiving Animal Wastes: II. Ammonia Volatilization. Trans. ASAE, 22(6):1398-1405.

Ree, W. U., F. L. Wimerley and R. W. Crow. 1977. Manning's n and the overland flow equation. ASAE Trans. 22(1):89-95.

Ross, B.B., D.N. Contractor, and V.O. Shanholtz. 1977. Finite element simulation of overland and channel flow. Trans. ASAE. pp. 705-712.

Schwab, G. O., R. K. Frevert, T. W. Edminster and K. K. Barnes. 1966. Soil and water conservation engineering, 2nd ed. John Wiley and Sons, Inc.

Sharpley, A. N. 1980. The enrichment of soil phosphorus in runoff sediments. J. Environ. Qual. 9:521-526.

Siemens, J. L. and W. R. Oschwald. 1976. Erosion from corn tillage systems. ASAE Trans. 36(4):902-904.

Siemens, J.L. and W.R. Oschwald. 1978. Corn-Soybeans tillage systems: Erosion control, effects on crop production, costs. Trans. ASAE. pp. 293-302.

Sinclair, R.G. 1973. Slow-release pesticide system. ES&T. 7(10):955-956.

Singh, B. B. and J. P. Jones. 1976. Phosphorus sorption and desorption characteristics of soil as affected by organic residues. Soil Sci. Soc. Am. J. 40:389-394.

Slack, C. H., R. L. Blevins and C. E. Rieck. 1978. Effect of soil pH and tillage on persistence of simazine. Weed Sci. 26:145-148.

Soil Survey Staff. 1975. Soil taxonomy, Agriculture Handbook No. 436. U. S. Supt. of Documents, Washington, D. C.

Stewart, B.A., D.A. Woolhiser, W.H. Wischmeier, J.H. Caro, and M.H. Frere. 1975. Control of water pollution from cropland. Vol I: A manual for guideline development. Agricultural Research Service. U.S. Department of Agriculture and U.S. EPA. Washington, D.C. ARS-H-5-1 and EPA 600/2-75-026a.

Stewart, B.A., D.A. Woolhiser, W.H. Wischmeir, J.H. Caro, and M.H. Frere. 1976. Control of water pollution from cropland, Vol. II: An overview. USDA and U.S. EPA, Washington, D.C. ARS-H-5-2 and EPA 600/2-75-026b.

Thompson, L.M. 1957. Soils and soil fertility. McGraw-Hill Book Co., New York. 2nd Edition. 451 p.

Triplett, G. B. Jr. and D. M. Van Doren Jr. 1969. Nitrogen, phosphorus and potassium fertilization of non-tilled maize. Agron. J. 61:637-639.

U.S. Environmental Protection Agency. 1979. BMP implementation plan for Four Mile Creek Project. Environmental Research Laboratory. Athens, Georgia.

U.S. EPA. 1980. Research summary: Integrated pest management. Office of Research and Development, Washington, D.C. EPA-600/8-80-044. 28p.

Van Doren, D. M. Jr. and R. R. Allmaras. 1978. Effect of residue management practices on the soil physical environment, micro-climate and plant growth. 49-83. In W. R. Oschwald (ed.) Crop residue management systems-ASA Spec. Publ. 31.

Voss, R. D. 1980. Nutrient use, removal, and soil test levels. In: 32nd Annual Fertilizer and Ag. Chemical Dealers Conference, Iowa State University Extension Publication No. EC-1498.

Walter, M.F., R.W. Hexem, P. Robillard, and R.B. Gilmour. 1979. Approach to selection of best management practices to control nonpoint sources of water pollution from agriculture in New York. Cornell University, Ithaca, New York.

Williams, J. R. and H. D. Berndt. 1977. Determining the universal soil loss equation's length-slope factor for watersheds., in G. R. Foster (ed.), Soil erosion: Prediction and control. Soil Conservation Society of America, Ankeny, Iowa. pp.217-225.

Willis, W. O. and M. Amemiya. 1973. Tillage management principles: soil temperature effects. In Conservation Tillage: The Proceedings of a National Conference. Soil Conserv. Soc. Am., Ankeny, IA. pp.22-42.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses, a guide to conservation planning. Handbook No. 537. U.S. Dept. of Agriculture. Washington, D.C. 58p.

Woolhiser, D.A. 1976. Hydrologic aspects of nonpoint source pollution., in B.A. Stewart et al., Control of water pollution from cropland, Vol. II. EPA-600/2-75-026b. U.S. EPA, Washington.

Yalin, Y.S. 1963. An expression for bed-load transportation. ASCE Hyd. J. 89(HY3):221-250.

APPENDIX

WORKING DEFINITIONS OF CANDIDATE BMPs

Nonstructural measures

1. No-tillage - A method of planting crops that involves no seedbed preparation other than opening the soil for the purpose of placing the seed at the intended depth. This usually involves opening a small slit or punching a hole into the soil. There is usually no cultivation during crop production. Chemical weed control is normally used. Also referred to as slot planting or zero tillage. Soil surface is generally protected by crop residues or sod.

2. Conservation tillage - Any tillage system which reduces loss of soil and water compared to unridged clean tillage. Reduction of soil and water loss is accomplished in most cases by reducing the extent of tillage and by protecting the surface with crop residues. Measures which may be considered conservation tillage include:

    a) till-planting - No preplant tillage is performed. Tillage is performed at time of planting with a till-planter. With this system, wide sweep and trash bars clear a strip over the old row, and a narrow planter shoe opens a seed furrow into which seed is dropped. A narrow wheel presses the seed into firm soil; covering disks place loose soil over the seed.

    b) chisel plowing - This system breaks or loosens the soil without inversion. Chisel plows are generally operated at depths equal to or slightly deeper than moldboard plows, usually 8 to 10 inches. When used in dry soils, chiseling loosens the soil and leaves up to two thirds of the residue at or very near the surface.

    c) disking - Accomplished by an implement called a disk harrow, disking can be used to perform primary or secondary tillage. Disk blades vary in size up to 30 inches in diameter, and each pass of a disk incorporates at least 30% to 70% of the plant residues. Disking permits incorporation of surface-applied nutrients and herbicides.

3. Contour farming - Conducting field operations, such as plowing, planting, cultivating, and harvesting, on the natural field contour. Due to its ineffectiveness on long

or steep slopes, contouring is often combined with strip cropping or terracing. Used in areas of 2-8% slope.

4. Graded rows - Where poor drainage or the likelihood of severe storms are a problem, rows on a slight gradient may be used rather than contouring to prevent breaking over of rows.

5. Contour strip cropping - The practice of growing crops in comparatively narrow strips of land on which the farming operations are performed on the contour. Strips of grass, close growing crops, or fallow are alternated with cultivated crops. Contour strip cropping implies both contouring and crop rotation.

6. Spring plowing - Delayed tillage from fall to spring can reduce soil erosion losses. Soil porosity at planting time is enhanced by spring tillage, and exposure of disturbed soil to wind, thaw runoff, and early spring rains is minimized.

7. Sod-based rotation - The inclusion of broadcast grass or legumes in the temporal crop rotation for an agricultural field. A typical rotation has been a few years of row crops, followed by one year of small grain, followed by at least three years of a sod crop such as alfalfa, followed again by row crops. Runoff and sediment loss is substantially reduced during the sod years.

8. Winter cover crop - A close growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production. A typical situation is a cover crop following corn silage on soybean harvest, if the crop leaves insufficient residue to protect the soil against erosion.

9. Permanent meadow - Topography or soil conditions may result in situations where other management practices are ineffective or too costly. In such cases conversion to permanent meadow may be the only solution.

10. Mechanical cultivation - Use of mechanical weeding devices. This practice reduces the need for herbicides, but results in disruption of land surface and dislodging of soil. This alternative represents an increase in cultivation from conventional practices.

11. Crop rotation - The growing of different crops in recurring succession on the same land. Rotations offer advantages for erosion, pesticide, and nutrient control. Deep rooted crops and crops with low nitrogen needs should be included in the rotation.

Structural measures

1. Terraces - Embankments or combinations of embankments and channels contructed across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope. Excess water is removed slowly from the field through nearly-level terrace channels to grassed outlets or is removed through a sub-surface drain. Eroded soil within the terrace interval accumulates in the terrace channel where more than 80% of it remains.

2. Diversions - Channels with ridges on their lower sides, constructed across the slope, for the purpose of diverting water from areas where it is in excess to sites where it can be used or disposed of safely.

3. Grassed waterways - Natural or constructed waterways, usually broad and shallow covered with erosion-resistant grasses, used to conduct surface water from cropland.

4. Filter strips - Strips of permanent vegetation above farm ponds, diversion terraces, and other structures to retard flow of runoff water, resulting in deposition of transported material.

5. Tile drainage - Removal of excess surface water or groundwater from land by means of surface or subsurface drains.

6. Retention basins - Localized depressions which serve as storage and settling areas for storm runoff.

Input Management Options

1. Improve soil fertility - Improving soil fertility increases crop yields and reduces soil erosion. Reduction in erosion is attributed to improved crop canopy, increased water use efficiency by plants, and the availability of more residue for soil protection.

2. Eliminate excess applications of nutrients or pesticides - Fertilizer and pesticide inputs into crop production should not exceed that needed for plant nutrient uptake and pest control. Fertilizer rates should be based on crop nutrient budgets which account for green legumes and manurial sources of plant nutrients.

3. Optimize timing of planting and chemical application - The least loss of nutrients from a field occurs when fertilizer

is applied as close to time of utilization by the crop as possible. Likewise, careful timing of pesticide application reduces the possibility of pesticide runoff. Thus the relative times of planting and chemical application can influence the uptake, effectiveness, and runoff of the applied chemicals. However, in Iowa a relatively narrow range exists for economic row-crop planting times.

4. Controlling release and chemical transformations - Methods of controlling the rate of release of nitrogen include (a) nitrification inhibitors, (b) coatings to retard the hydrolysis of urea to NH_4-N and (c) inhibition of urease activity in soil. Selection of chemicals with favorable half-life and adsorption properties is included in this option.

5. Biological control - Included in biological management measures are: (a) use of pest resistant strains of crop and (b) utilization of natural enemies of a pest for control (predators, disease).

6. Incorporation of applied chemicals - Fertilizers or pesticides are applied to the land surface, and tillage is performed to incorporate the chemicals into the soil. In some cases, incorporation is performed by the application equipment.

HSPF and Corresponding ARM Model Parameters Related to Processes Impacted by BMPs *

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Runoff-related			
Interception	CEPSC(M)	EPXM	Interception storage capacity. Values in ARM vary with monthly crop cover.
Depression/Surface Storage	UZSN(M)	UZSN	Upper Zone Nominal Moisture Capacity.
Soil Moisture Storage	LZSN	LZSN	Lower Zone Nominal Moisture Capacity.
Overland Flow	LSUR	L	Length of overland flow path.
	SLSUR	SS	Slope of overland flow path.
	NSUR(M)	NN	Manning's n of overland flow path.
Infiltration	INFILT	INFIL	Index to infiltration capacity of soil.
	INFEXP	none	Exponent in infiltration equation. Value of 2.0 is used in ARM.
	INFILD	none	Ratio of max to mean infiltration capacities of the soil. Value of 2.0 is used in ARM.
Subsurface Flow	INTFW(M)	INTER	Interflow inflow parameter.
Evapotranspiration	LZETP(M)	K3(M)	Lower zone ET parameter.
Snowmelt	SNOWCF	SCF	Snow catch parameter to account for poor catch efficiency of gage.

Note: There are many more snow parameters, but it is uncertain which ones would vary with BMPs.

* : Parameters followed by '(M)' indicate that 12 monthly values can be specified.

HSPF and Corresponding ARM Model Parameters (continued)

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Sediment-related			
Detachment by Rainfall	COVER(M)	COVPMO(M)	Monthly crop canopy parameter.
	KRER	KRER	Coefficient in soil detachment equation.
	JRER	JRER	Exponent in soil detachment equation.
	SMPF	SMPF	Supporting management practice factor.
Detachment/scour by overland flow	KGER	none	Coefficient in matrix soil scour equation.
	JGER	none	Exponent in matrix soil scour equation.
Transport by overland flow	KSER	KSER	Coefficient in sediment transport equation.
	JSER	JSER	Exponent in sediment transport equation.
Delivery to stream	No specific parameter		
Gully Erosion/scour	KGER	none	Gullying is included in the soil
	JGER	none	scour equation.
Availability/Production of soil fines	DETS	SRERTL	Soil fines produced by tillage.
Aggregation/Compaction	AFFIX	SCMPAC	Daily reduction in detached soil fines due to compaction/ settling.
	NVSI(M)	none	Daily atmospheric accumulation/ removal of soil fines (positive or negative)

HSPF and Corresponding ARM Model Parameters (continued)

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Chemical-related:			
Availability/Input (Surface & Sub-surface)	Note: Chemical applications are represented in HSPF by incrementing the storage values shown below by the application rate at the time of application.		
Pesticides:	SPS(3) UPS(3) IPS(3) LPS(3) APS(3)	PSSZ PSUZ none PSLZ PSGC	Pesticide storages in surface (S), upper (U), interflow (I), lower (L), and groundwater (A or G) zones. HSPF allows for crystalline, adsorbed, and solution states in all but interflow.
Nitrogen:	SN(5) UN(5) IN(2) LN(5) AN(5)	Storages are specified for each form in each soil layer except interflow	Five N forms (OrgN, NH3-A, NH3-S, NO3, PLANT-N) are specified for each layer, except that interflow has only NO3 and solution NH3.
Phosphorus:	SP(4) UP(4) IP(1) LP(4) AP(4)	(analagous to nitrogen)	Four P forms (Org P, PO4-A, PO4-S, PLANT-P) are specified for each layer and only PO4-s for interflow storage
Transformations			
Nitrogen:	KDSAM KADAM KIMNI KAM KDNI	KAS KSA KKIM KAM KD	NH3 desorption NH3 adsorption NO3 immobilization Org N ammonification Denitrification

HSPF and Corresponding ARM Model Parameters (continued)

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Transformations			
Nitrogen:	KNI	K1	Nitrification
	KIMAM	KIM	NH3 immobilization
	NO3UTF	none	Fraction of plant uptake from NO3
	NH4UTF	none	and NH4; sum is equal to 1.0.
	THKDSAM	THKAS	Temperature correction (THETA)
	etc.	etc.	values for each reaction designated by TH in front of the reaction name.
	CMAX	none	HSPF allows option to use Freundlich
	XFIX	none	equilibrium calculations for NH3
	K1	none	adsorption instead of 1st order
	N1	none	kinetics. These parameters are the solubility, irreversible adsorption, K, and N values.
Phosphorus:	KDSP	KAS	PO4 desorption
	KADP	KSA	PO4 adsorption
	KIMP	KIM	PO4 immobilization
	KMP	KM	Org P mineralization
	THKDSP	THKAS	Temperature correction (THETA)
	etc.	etc.	values for each reaction rate
	CMAX	none	(See note above for corres.
	XFIX	none	nitrogen parameters.
	K1	none	
	N1	none	

HSPF and Corresponding ARM Model Parameters (continued)

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Uptake/Degradation			
Pesticides:	SDGCON	KDG	HSPF allows different degradation
	UDGCON	KDG	rates for each soil layer,
	LDGCON	KDG	surface (S), upper (U), lower (L),
	ADGCON	KDG	and groundwater (A)
Nitrogen:	KPLNM(M)	KPL, ULUPTK LZUPTK	Plant uptake of nitrogen. HSPF allows monthly rates for each soil layer.
Phosphorus:	KPLPM(M)	KPL, ULUPTK LZUPTK	Plant uptake of PO4. HSPF allows monthly rates for each soil layer.
Pesticide Adsorption/ Desorption	CMAX	CMAX	Maximum solubility
	XFIX	DD	Pesticide permanently fixed to soil.
	K1	K	Freundlich K value
	N1	N	Freundlich N value
	N2	NP	Freundlich N value for non-single-valued adsorp./desorp. option. Note: HSPF allows these parameters to vary with each soil layer.
	KDSPS KADPS	none	1st order rate parameters for pesticide adsorption/desorption. This is an additional option in HSPF.
	THDSPS	none	Temperature correction (THETA)
	THADPS	none	values for pesticide 1st order A/D rates.

HSPF and Corresponding ARM Model Parameters (continued)

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Other:			
Soil Temperature	ASLT(M)	ASZT	Intercept (ASLT) and slope (BSLT) of surface layer temperature
	BSLT(M)	BSZT	regression equation related to air temperature.
	ULTP1(M)	AUZT	Intercept (ULTP1) and slope
	ULTP2(M)	BUZT	(ULTP2) of upper layer soil temperature regression equation.
	Note: In HSPF, upper layer soil temperature can be modeled with a regression equation as defined above or with a smoothing algorithm with parameters redefined as follows:		
	ULTP1(M)	none	Smoothing factor
	ULTP2(M)	none	Mean difference between soil and air temperatures.
	LGTP1(M)	LZTEMP(M)	Monthly lower and groundwater layer temperatures at start of each month.
	Note: The smoothing algorithm option is also available for the lower and groundwater layers with the following parameters:		
	LGTP1(M)	none	Smoothing factor
	LGTP2(M)	none	Mean departure from lower/ groundwater soil temperature and air temperature.

HSPF and Corresponding ARM Model Parameters (continued)

PROCESS	HSPF PARAMETER	CORRESPONDING ARM PARAMETER	COMMENT
Other:			
Soil Depths	Surface Layer	SZDPTH	Thickness of the assumed soil layers. In ARM,the lower layer is 6 feet, and UZDPTH is the total depth from the surface to the bottom of the upper layer.
	Upper Layer	UZDPTH	
	Lower Layer	none	
	GW Layer	none	
Bulk Densities	Surface Layer	BDSZ	Bulk densities for each soil layer. HSPF does not assign a name to the bulk density or soil depth parameters.
	Upper Layer	BDUZ	
	Lower Layer	BDLZ	
	GW Layer	none	